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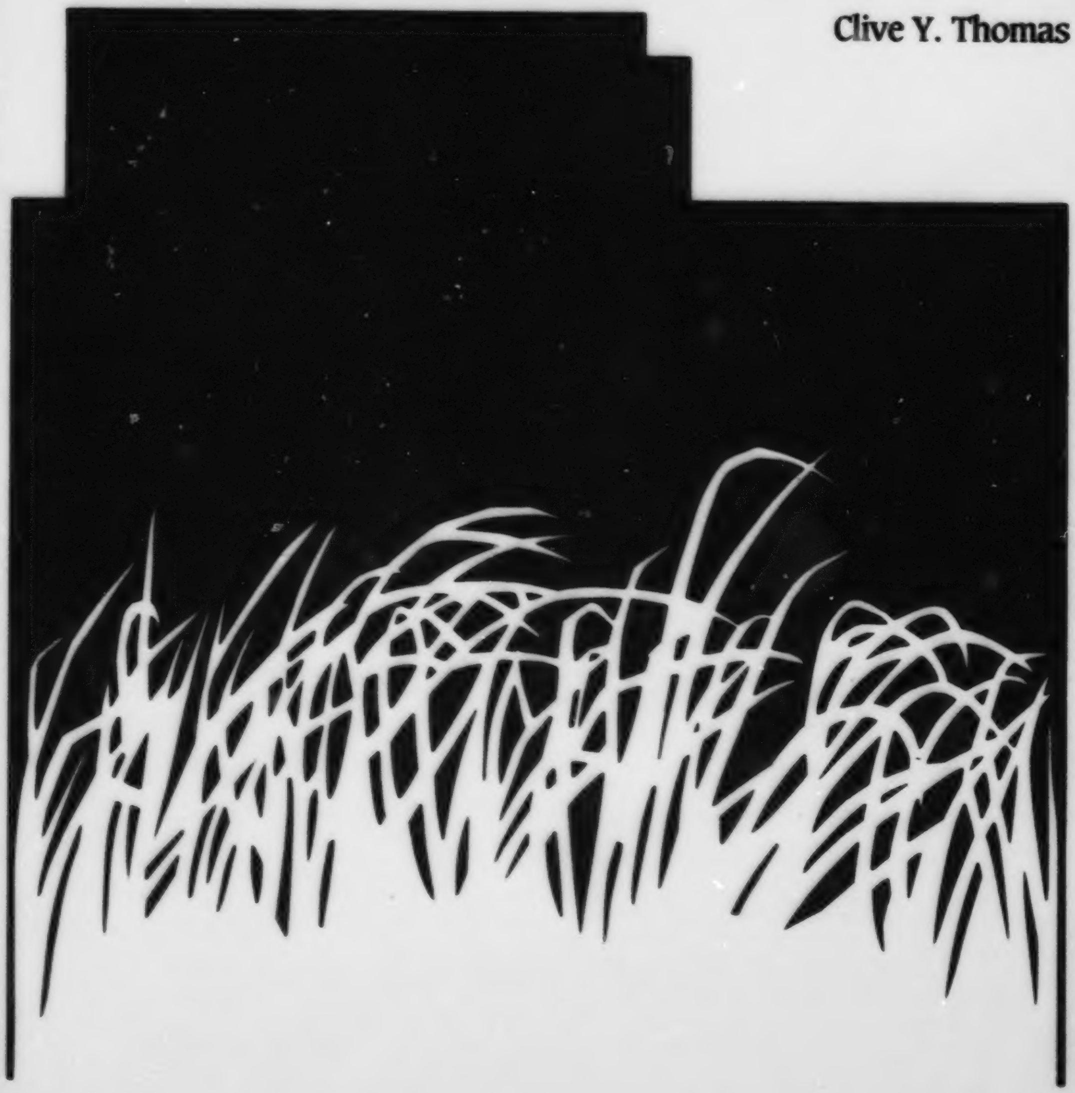
Sugar

Threat or Challenge?

An assessment of the impact of technological developments in the high-fructose corn syrup and sucrochemicals industries

Clive Y. Thomas



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An Assessment of the Impact of Technological Developments in the High-Fructose Corn Syrup and Sucrochemicals Industries

Clive Y. Thomas

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Abstract

This study assesses the "threat" to the traditional role of sucrose as the leading sweetener brought about by several technological innovations and the "challenges" afforded by similar innovations in sucrochemistry. The major threat derives from two sources: the commercialization of high-fructose syrup made from corn, and its possible extension to other carbohydrate sources; and the development of a new generation of noncaloric sweeteners, principally Aspartame.

The "challenges" derive from efforts to replace petroleum (a "finite" resource) as the world's principal chemical feedstock with sucrose (a "replenishable" resource). This has led to a new field of science, "sucrochemistry" whose essence is to treat sucrose not as a sweetener but as a chemical product that can be transformed into other chemicals of greater worth. The promise of a radical departure from the traditional sequences of industrialization of tropical staples exists, and its implications for developing areas and the Caribbean are drawn.

Résumé

L'étude porte sur la «menace» pour la saccharose, principal édulcorant, que posent les innovations technologiques et les «défis» provenant d'innovations semblables en sucro-chimie. La plus grande menace provient, en premier lieu, de la commercialisation de sirop de maïs à haute teneur en fructose et de l'extension éventuelle de cette commercialisation à d'autres sources de glucides et, en second lieu, de la production d'une nouvelle génération d'édulcorants sans calorie, en particulier, l'Aspartame.

Les «défis» proviennent des tentatives de remplacement du pétrole (ressource «épuisable»), le plus important produit de base en chimie, par la saccharose (ressource «inépuisable»). De ces tentatives est née la «sucro-chimie», qui, essentiellement, traite la saccharose non comme un édulcorant, mais comme un produit chimique transformable en d'autres produits chimiques de plus grande valeur. La réorientation de l'industrialisation des produits tropicaux de base, promesse de cette nouvelle science, est réelle et ses conséquences sur les régions en développement, ainsi que sur les Antilles, sont décrites.

Resumen

En este estudio se analiza tanto la posible disminución de la demanda de azúcar, el edulcorante tradicional más importante, debido a la introducción de nuevos substitutos, fruto de las innovaciones tecnológicas, como la diversidad de usos que auguran los avances en el campo de la sucro-química. Los substitutos que hacen mayor competencia al azúcar son el jarabe con elevado contenido de fructosa derivado del maiz — y quizás de otràs fuentes de carbohidratos en el futuro; y la nueva generación de edulcorantes no calóricos, el más importante de los cuales es el Aspartamo.

La diversidad de posibles usos que cabe esperar son resultado de los esfuerzos realizados para hacer de la sucrosa (recurso renovable) la principal fuente de alimentos sintéticos a nivel mundial, reemplazando así al petróleo (recurso limitado). Esto ha llevado a la constitución de una nueva ciencia, la "sucro-química," para la cual la sucrosa no es un edulcorante sino una substancia química que puede transformarse en otros productos químicos de mayor valor. En este estudio se analiza el cambio radical que esto podría representar con respecto a los pasos tradicionales en la industrialización de los principales productos tropicales y sus posibles consecuencias en los países en desarrollo y el Caribe.

Contents

Acknowledgments 4

Foreword 5

Introduction 7

Part I The Threat — the Technological Impact of High-Fructose Corn Syrup 11

Chapter 1 Salient Characteristics of the World Sweetener Industry 13

Chapter 2 Innovation in a Mature Industry: The Case of HFCS 23

Chapter 3 Structure of the HFCS Industry 39

Chapter 4 Economics of HFCS Production 59

Chapter 5 HFCS and the Future: An Assessment 69

Part II The Challenge — the Technological Impact of Sucrochemicals 79

Chapter 6 Industrial Uses of Cane Sugar By-Products 81

Chapter 7 Potential of Sucrose as a Chemical Feedstock 85

Chapter 8 Historical Functional Analysis of the Development of Sucrochemicals 95

Chapter 9 Sucrochemicals: Some General Issues 101

Chapter 10 Sucrochemicals and Transnational Enterprise 111

Chapter 11 The Threat and the Challenge: An Assessment 127

References 136

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Pursuing research of this nature in the context of limited library materials, as is the situation at the University of Guyana, has forced me to rely very heavily on friends and colleagues abroad to acquire relevant materials at short notice. All of these have responded well beyond my expectations, but I would like to single out Dr Bhisnoodath Persaud, of the Economics Division of the Commonwealth Secretariat, who has in every single instance I have turned to him managed to secure and send data to me in what appeared to be almost literally overnight.

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A study of this nature inevitably requires that the cost of my preoccupation has had to be borne by my family, friends, and all those close to me. To them I am indebted, and I trust that they understand the imperatives that make work of this sort a continuing human endeavour.

Foreword

The Science and Technology Policy Program of the International Development Research Centre supported two major studies on technology policy choices facing the countries of the Caribbean. The first set of studies was undertaken between 1975 and 1979. These studies were among the first to examine issues of transfer of technology in the region and in countries with small industrial and economic bases. Among the conclusions was a recognition that the formulation of a technology policy involved the specification of the socioeconomic objectives; an evaluation of local resources, human and natural, and their deployment; and an international search for the most appropriate technology, together with a simultaneous program of local research and development. It was clear that the Caribbean countries faced unique problems in their attempts to build an appropriate economic and science and technology policy.

A second phase of research, which stemmed directly from the results of the earlier studies, was supported by the Centre between 1980 and 1983. A specific objective was to examine in detail the technological potential of a few important economic sectors based on their current patterns of technological usage and future technical options. In this publication, the results of one of these studies is presented.

The cultivation of sugarcane has shaped the history of the Caribbean and continues to be important to the region's economy in terms of investments, employment, production, and trade. A crucial public policy question confronting the Caribbean relates to the future technological and market trends for sugar from cane and the need to assess the future of the sector keeping in view the negative social impact associated with its decline. The prevailing price for sugar in international markets over the past few years makes any plan of reviving the sugar economies of the Caribbean seem an unrealistic wish.

It is in this context that this study is of importance not only to the Caribbean but also to many other developing countries that rely on the production of sugar. The study examines aspects of the global sugar trade and the protective barriers erected in North America and Europe and their enormous impact on the income of the sugar-producing countries. These issues are only briefly dealt with as they have been covered extensively elsewhere. A more important contribution of this study is to establish clearly the extent of the decline in the use of cane sugar as a sweetener because of the combination of trade restrictions, market preferences, and technological change.

The study then reviews the recent developments in sucrochemical technology and assesses the potential of sugarcane, an efficient producer of biomass, as a base for a sucrose-based chemical industry. It is not possible in such a study to determine with precision the technoeconomic viability of the alternatives and, hence, specific investment implications. Dr Thomas, however, has presented an excellent exploration of the different technological options available for sugarcane, which will be important for policymakers not only in the Caribbean but also in other countries with significant production of sugarcane.

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Introduction

Cane Sugar — End or New Beginning?

The history of sugarcane cultivation in the tropics has been a long and turbulent one associated with slavery, indenture, war, conquest, colonization, and some of the worst brutalities ever practiced. Many have pondered the irony in the question "how could so much sweet be the cause of so much bitterness?" Today, in many parts of Latin America, the sugarcane plant is still known as the "hunger crop," because, in many of these countries, although it is frequently cultivated on the best soils, it is just as frequently associated with starvation, low wages, irregular employment, and lack of job security. It is still possible for a labourer to work for 20 or more years on many sugar estates and be classified as a "casual employee."

Until about a decade ago, the one major surviving challenge to the supremacy of the sugarcane plant has been the rise of substitute sucrose production from beets. Today, at the peak of concerted efforts by the European Economic Community (EEC) countries to expand beet sugar production, sugar or sucrose produced from the sugarcane plant accounts for about 60% of the worldwide output of sugar. Over the past decade or so, however, a new challenge has been posed to cane and beet sugar alike. This has come from the development of the high-fructose corn syrup industry, known as HFCS or isoglucose in Europe. As we shall see in some detail later, this product has come about because of major technological developments in a number of areas (chemical, biotechnical, genetic engineering, etc.) that have led to the production of a commercially successful sweetening agent from maize, with the possibility of its extension to other carbohydrate sources (cassava, rice, etc.). Already this product accounts for more than 25% of all nutritive sweeteners used in the United States.

Over the years, the major hindrance to the rapid expansion of sucrose consumption has been the fear of its consequences to health, particularly its association with obesity. This has meant that there has always existed a huge market for a sweetening agent, artificial or natural, that has an acceptable taste (and other characteristics to be discussed later) and that contains few or no calories and has no adverse health effects. The diet foods and beverages industry is presently dominated by the use of saccharin. Even though its widespread use has been condemned by national drug standards agencies in several countries because of its link to various cancers, its consumption still accounts for several billion dollars of sales world wide. Recently, a new sweetener, Aspartame, has been proclaimed as the long sought after substitute and already is being marketed in several countries. This new product poses a challenge not only to cane and beet sugar but to all widely used sweeteners including HFCS and saccharin.

Even as these new threats to the established sugar industries appear, the possibility of a new beginning for sucrose looms on the horizon. Propelled by rising prices of petroleum products, as well as growing concern over the natural limitations inherent in the use of "finite resources" in widely consumed commodities, the search has been focused on replacing many of the petroleum-based products currently in use with products made from a replenishable source. Out of this has emerged the area of technological and industrial development known as sucrochemistry. This new field of endeavour does not constitute either the "simple" industrialization of the by-products of the sugarcane plant, which is still important, or the production of the sugarcane plant for "nontraditional uses," e.g., high-test molasses, animal feeds, ethanol, but the use of sucrose itself as the feedstock for a chemical industry. This new beginning, therefore, involves a qualitative break with the traditional development and industrialization of a tropical staple (with all the difficulties this implies) and leaps to the very frontiers of knowledge and new technological processes. From every side this link with the frontiers of new science and technology cannot be avoided by the cane sugar producers, because, as I have already indicated, the emergence of its new competitors (e.g., HFCS and Aspartame) has also been based on the development of modern biological science, enzyme technology, and so on.

This study assesses the "threat" posed by technological developments in the HFCS industry to the world sugar industry and the "challenges" held out by similar developments in the sucrochemicals industries. This is, however, not a study of the world's sugar industry in general (or more accurately the sweetener industry) or that of the Caribbean in particular. It deals instead with the sugar (sweetener) industry from two angles: the development of HFCS on the basis of recent technological innovations and the threat that this poses to the world's traditional sweetener industry in general and the Caribbean's in particular, and the opportunities being created by recent technological advances in the field of sucrochemicals. It is from this conceptual approach that the title of the study has been derived — "threat or challenge." It should be appreciated even at this early stage, therefore, that this study is not the simple aggregation of two different studies of the same industry or the study of two entirely different industries. The interface between technological developments and their applications in the HFCS and sucrochemical industry is a matter of central concern. Indeed, because the same transnational corporations (TNCs) are frequently involved in traditional sugar production (cane and beet), other sweeteners, HFCS, and sucrochemicals, any attempt to isolate the two areas of the study, or treat them merely additively, would be very unwise.

This study originated as part of the second phase of the Caribbean Technology Policy Studies Project, which is a comprehensive joint project of the University of Guyana, University of the West Indies, and the International Development Research Centre (Ottawa) (IDRC). The description given here is more than the usual formal one because the research work underlining this study has been executed entirely within the framework of the project. As a result, the significance of what has been attempted here may well be only fully appreciated in the overall context of the principal aims of this project, which are to examine the issues of indigenous technological capability; search evaluation and bargaining; science and technology policy planning; and size, scale, and technological transformation of the Caribbean. Within these overlapping aims, this study fits into the specific area of the technological impact assessment studies undertaken by the project in the area of science and technology policy planning. In this area of the project, the objective is to evaluate, from the perspective of the concerns of the Caribbean and similar regions, certain fundamental technological transformations that have been occurring on a world scale with a view toward developing a technological planning capability to cope with them. The leading edge in the development and application of new technology in the case of the HFCS industry is the U.S., and to a lesser extent Japan, the EEC, Canada, and certain territories in Southeast Asia and Latin America. The study naturally focuses on these territories, but the predominant concern is with the U.S. where 11 firms and some 17 plants make up the overwhelming bulk of the world's resources currently committed to HFCS production.

In the case of the sucrochemicals industry, the leading edge of technological innovations is located in a U.K.-based TNC, Tate and Lyle Ltd. Here considerable focus will naturally fall on this enterprise.

In pursuit of this study a number of subthemes of some general significance are briefly touched upon from time to time, the principal ones being

- Innovation and response in a mature industry concerned with agricultural production and processing (maize and cane sugar),
- The industrialization of a traditional tropical staple outside of the traditional area of greater by-product utilization,
- The uniqueness of the circumstances of sugar production created by the competition between developed and developing regions in producing a widely consumed commodity whose importance to the various national economies producing and consuming it varies considerably,
- Renewable (biomass material) versus finite resources (mainly petroleum) in industrial development,
- Land use for food versus manufacturing output in the industrialization of agricultural crops, and
- The role of government policy in the development of technology and its application.

Concern over a possible diversion from the main thrust of the study has in some instances limited intervention on these issues to a few hints.

In conclusion, it should be noted that relatively little accessible work has been done on the HFCS industry, and far less on the sucrochemicals industry. Thus, one of the major aims of the study is to contribute to the enlargement of the information pool and increase its accessibility and availability. Such an enlargement is an indispensable requirement, if systematic monitoring of technological developments is to take place. As argued in the study, this is an extremely critical science and technology planning function. Part I of the study deals with HFCS (the threat) and Part II with sucrochemicals (the challenge).

Part I is divided into five chapters. The first outlines the salient characteristics of the world sweetener industry. This chapter introduces the concept of sweetener as the background for evaluating cane and beet sugar, HFCS, other corn-based sweeteners as well as the noncaloric, synthetic sweeteners. It also introduces the reader to the general position of the sugar industry in the Caribbean and the organization of the world market for sweeteners. The second chapter traces the development of HFCS technology. The third examines the global structure of HFCS industry and the fourth examines the economics of producing this commodity. The final chapter in Part I of the study (Chapter 5) gives an assessment of the impact of the new product and outlines a strategy that a region like the Caribbean could use to deal with the present situation.

Part II is divided into six chapters. The first of these (Chapter 6) looks at the industrial uses of cane sugar by-products, even though this is not of immediate concern to the study. It is important, however, for setting the stage for the later examination of sucrose itself as a chemical feedstock. The potential here is outlined in Chapter 7. Chapter 8 traces the development of sucrochemicals technology, and Chapter 9 looks at some general economic issues arising out of the present stage of technological development. Chapter 10 examines the recent experiences of the TNC of Tate and Lyle Ltd, as the leading enterprise in this field. The final chapter of the study (Chapter 11) gives not only an assessment of the promise held out by sucrochemistry, but puts sugar in the context of both the threat and the challenge.

Part I

The Threat — the Technological Impact of High-Fructose Corn Syrup

Chapter 1

Salient Characteristics of the World Sweetener Industry

Sugar in the Caribbean

The labels "plantation economy," "sugar economy," "King Sugar," etc., which have been used frequently to describe the English-speaking Caribbean economies, are testimony to the importance that sugar has played in the historical development of the region. The sugar industry is a direct product of European colonial conquest and settlement of the area and, from the inception, cane sugar cultivation and processing were confined to the production of raw sugar, which is the sucrose stage of about 95% purity, for export from the region.

Because the cultivation of the sugarcane plant has been almost single-mindedly focused on the production of sucrose, only the limited utilization of some by-products has occurred, e.g., bagasse as fuel, molasses for home use or direct export as animal feed, and the production of alcohols, mainly rum. Whatever resources have been allocated to local research and development (R&D) have been largely concentrated in the areas of propagation of sugarcane varieties, their cultivation practices, and disease and pest control; machinery and equipment repair and the maintenance of the sugar processing factories; and transportation, construction, earth moving, and other problems dictated by the specific topography of the areas where sugar is produced. As a result, sugar has been very instrumental in the creation of a particular dynamic of material production that characterizes the region, which I have described elsewhere as producing what it does not consume and consuming what it does not effectively produce, thereby denying a real (i.e., physical resource) imperative or social (i.e., needs/demand dictated) imperative for the development of an indigenous logical technocapability (Thomas 1974).

After centuries of dominating Caribbean economic and social life, the development of the region's sugar industry peaked in the 1960s. By then, however, social and political transformation in the region, in particular the nationalist movement toward independence, the rise of trade unionism, and increased land pressures leading to a greater assertiveness of the peasantry in demanding land and other resources, had created new priorities in the focus of development. These newer priorities have led to a greater role of the state in development and an increased emphasis on tourism, mineral development, and import-substituting activities behind domestic protective barriers. In turn, the latter activities have resulted in manufacturing- and agroprocessing-oriented transnational corporations (TNCs) playing major roles in the region's economy. As a result these complex processes have brought about a general decline in the importance of sugar in the region's economy.

In the early 1960s the region was producing more than 1.3×10^6 t of sugar, with exports ranging from 80 to 90% of this total output. Currently, the region is producing about 0.7×10^6 t of sugar, which is about one-half of the 1960 output, and exporting about 80% of this amount. In all the major territories, production has fallen. In Barbados, the 1983 output (85 000 t) was about one-half the output level of 160000 t reached in the early 1960s. This was the lowest output level attained since 1948. Acreage reaped had fallen from more than 61 000 acres to 36000 acres (24 705 ha to 14 580 ha) in 1983. As the Prime Minister remarked in a statement to Parliament on 13 July 1982:

> I have to report to the House and Nation that 1982 has been as catastrophic a year for the sugar industry as was 1981. In 1981 the problems were those of a late start of the crop and unseasonable weather. . .in 1982 the problems appear to be those of morale in the widest sense.

In 1984, there was a slight improvement when output reached just over 100000 t. In Guyana, output in 1984 was about 250000 t compared to about 370000 t in the 1960s. In Trinidad and Tobago, 1984 output totaled 64000 t compared to more than 240000 t of sugar produced in the 1960s. This output level was also the lowest recorded since the end of World War II. In Jamaica, output currently averages more than 200000 t compared to output levels of 450000 t achieved in the 1960s. It is only in Belize that output has been expanding steadily, from around 25000 t 20 years ago to about 120000 t for 1984, and is projected to reach 150000 t by the end of the decade. In St Kitts, where the industry is being revived, output currently averages 35000 t. Although the region produces sugar for export, it still imports 80000–90000 t of refined sugar; about 45% of this is produced by Trinidad and Tobago alone. Most of the sugar exported from the region goes to the European Economic Community (EEC), where it is marketed under the EEC–ACP (African, Caribbean and Pacific States) Sugar Marketing Protocol, to the U.S. where it enjoys quotas and General System of Preferences (GSP) status, and to Canada where it obtains preferential status. The remainder of the exports go the "world market." There is also a small amount of intraregional trade in sugar and in general within the region domestic sugar requirements equal 250000 t.

Certain characteristics of the decline in sugar production in the region are given in Table 1 where productivity data show the drastic declines in the yields of cane and sugar per acre (1 acre = 0.405 ha) and the conversion rate of sugarcane to sugar. Thus, the highest yield of sugar per acre in 1983 (2.4 t in Barbados) was about 30% lower than the highest yield in 1960 (3.4 t in Guyana). The lowest yield in 1960 (2.9 t in Trinidad and Tobago) was 40% above the lowest yield in 1983 (1.7 t also in Trinidad and Tobago). The factory efficiency ratios (tonnes cane–tonne sugar) also show that in Guyana in 1983 as much as 13.6 t of cane was required to produce 1 t of sugar that is 25% worse than the least efficient ratio in 1960 (10.9 t cane : 1 t sugar also in Guyana).

The performance of sugar reflects the overall decline of agricultural output and productivity in the region. Thus, comparative data on value added in the agricultural sector and per capita food production for the larger territories of the region as shown in Tables 2 and 3 indicate the extent of the decline over the past decade. These figures reveal that in Guyana for 6 of the 10 years the index of per capita food production was less than 100 (base period production 1960–71); in Jamaica this was so for 8 of the 10 years and in Trinidad and Tobago this was the case for every year during the decade. Similarly, the value added data show substantial declines in the contribution of the agricultural sector to gross domestic product (GDP), most notably in Barbados and to a lesser extent in Trinidad and Tobago. In the latter case, oil has tended to dominate the economy, and the agricultural sector's contribution to GDP during 1961–70, even before the oil boom, was only about 5%. One consequence of this is that despite being a food exporter the region has a very negative food balance and currently imports nearly US$1 billion worth of food and feeds.

The years following the tremendous boom in the world sugar prices of 1973–74 witnessed crucial developments in the region's sugar industry. The

Table 1. Comparative productivity data for major Commonwealth Caribbean sugar producers, 1960–83.

	1960	1980	1981	1982	1983
Tonnes cane : tonne sugar					
Barbados	9.0	9.2	10.3	9.4	8.5
Guyana	10.9	12.8	13.1	12.6	13.6
Jamaica	10.3	11.0	12.0	12.5	11.8
Trinidad and Tobago	10.1	13.1	13.9	15.0	12.9
Cane yield/acre					
Barbados	29.2	30.3	24.7	20.7	20.3
Guyana	38.2	28.3	29.3	28.7	28.9
Jamaica	31.4	23.8	21.6	23.9	23.4
Trinidad and Tobago	29.9	23.0	25.6	22.0	21.5
Sugar yield/acre					
Barbados	3.3	3.3	2.4	2.2	2.4
Guyana	3.4	2.2	2.2	2.3	2.1
Jamaica	3.0	2.2	1.8	1.9	2.0
Trinidad and Tobago	2.9	1.8	1.8	1.5	1.7

Note: 1 acre = 0.405 ha.

Table 2. Indices of per capita food production, 1971–80 (1960–71 = 100).

Country	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Guyana	102	90	89	100	100	94	99	104	92	88
Jamaica	102	100	98	96	93	92	89	92	90	90
Trinidad and Tobago	91	97	88	90	95	96	95	90	87	79

Source: As quoted in the 1980–81 Annual Report of the Inter-American Development Bank.

Table 3. Percentage contribution of the agricultural sector to GDP, by country, 1960–83.

Country	1961–70	1971–75	1976	1977	1978	1979	1980	1981	1982	1983
Barbados	22.0	11.2	10.9	10.8	10.5	10.8	10.8	8.3	9.4	9.5
Guyana	22.2	18.5	16.2	16.4	18.4	17.7	18.6	17.6	20.6	19.3
Jamaica	9.8	7.6	7.9	8.6	9.5	9.0	8.6	8.2	7.7	8.1
Trinidad and Tobago	5.4	4.4	3.6	3.4	3.1	3.4	2.4	2.3	2.3	2.3

Source: Annual Reports of the Inter-American Development Bank, 1980–81, and for the years 1981–83, Annual Report, 1984.

collapse of the unsustainable sugar prices of that period coincided with the end of the protected marketing arrangements of the Commonwealth Sugar Agreement (CSA) after a quarter of a century, and the establishment of the far less favourable Lome Convention, EEC–ACP Sugar Protocol. Unlike the CSA, this agreement is not based on the formula of cost-of-production plus a profit that reasonably efficient producers used to determine the price of sugar imported from the ACP countries, but instead the prices paid are strongly linked to the internal regulation and subsidization of EEC beet sugar production. As will be discussed more fully later, the policy of subsidies to the EEC beet sugar industry has resulted in the EEC emerging as not only a major consumer and importer of sugar but a major producer and exporter as well. This has created pressures on the prices paid and the quantities of ACP sugar imported by the EEC. The difficulties these countries claim to face under the Lome protocol are graphically summed up in this statement made by the marketing Director of the Guyana Sugar Corporation (MacDonald 1979):

> First of all, we have a quota in the EEC instead of the old CSA quota. Now I am not underestimating the vital importance of the EEC quota to us in Guyana. Our quota of 167 000 tons represents a guaranteed market for over half our export sugar, and the price currently is much above the world price. But somehow the sanctity of this quota has to be fought for day in, day out, in a way we never had to fight for the CSA quota. Sometimes one feels like a man running backwards and forwards along an endangered dam, patching and patching, as French beet farmers, bureaucrats in Brussels, and unsympathetic European pressure groups of all sorts, who do not know or hardly care about our circumstances, try to punch holes in the dam and let the whole structure wash away. Prices are imposed, not negotiated. You have the feeling that you are fighting a war that never ends, even though you thought the peace was made and signed and sealed in the Lome Sugar Protocol.

In addition to the considerations already mentioned, two other points are worthy of note in evaluating the present state of the region's industry. One is that after the expiry of the U.S. Sugar Act, protection was reimposed for U.S. domestic sugar producers, after 7 years of a more or less free market situation, except for the General System of Preferences exemptions given to some countries exporting to the U.S. market. The recent protection has transformed the U.S. market into an attractive preferential one, certainly when compared with the "free market," as current prices are four to five times the "world price."

When it was first introduced in 1982, the U.S. government stated that the protection was a temporary measure. Quarterly quotas were announced at first, but during October 1982 an annual quota was fixed in which the Caribbean obtained a regional quota of 151 000 t out of the 2.8×10^6 t fixed globally. Although this development contrasted strongly with the free market, deregulation ideology of the U.S. administration, it shows the power of special political considerations when considering the marketing of sugar. The protection afforded by this market, like that in the EEC, faces constant erosion as domestic developments in the U.S. sweetener industry with the trend against sugar consumption operate against the region. This has resulted in lower and lower global and regional quotas. The other important consideration affecting the region's industry has been the tremendous increase in oil prices that started in 1973–74 and its associated global inflation of prices combined with the more or less persistent global recessionary tendencies since then.

Because of these circumstances the region's sugar industry can truly be summed up as being at a critical juncture. Despite the tendency for debts and costs to rise and for output to decline, however, a significant part of the region's resources is still involved in sugar. In Barbados and Guyana, sugar earns about one-third of their foreign exchange, but in Guyana, sugar is the largest single employer of wage labour. Furthermore, when examined closely, the indicated decline in the region's sugar output has been due more to declines in output per man-hour worked, yields of sugarcane per acre, and the conversion efficiency of the factories (from sugarcane to raw sugar) than to the curtailment of land areas and a reduction in total factory capacity. Thus, total area reaped between 1981–83 averaged 335000 acres (135675 ha) for the four major territories as compared with 370000 acres (149850 ha) in 1960. Also in Guyana, the rated capacity of the sugar industry is 450000–500000 t/year, compared to current output of about half that. In Trinidad and Tobago current output is also about one-half the industry's potential. The declines in sugar output, therefore, although large, still understate the true loss in importance of sugar to the Caribbean region.

Many of the difficulties facing the region's sugar industry stem from uncertainty over the future directions of public policy. This is crucial because in all the territories the state has assumed a larger role in the industry's production, processing, and marketing of sugar. In the cases of Guyana, Trinidad and Tobago, and Jamaica, through nationalization and other localization measures adopted in the 1970s, the governments own and control the bulk of the resources of this sector. From all indications, however, the governments of the region are uncertain as to whether to pursue the expansion of sugar production or not. The strongest argument in favour of expansion is of course the existence of significant resources already committed to this industry and the momentum and pressures this naturally creates to ensure further growth and development. At the same time, however, huge losses and enforced subsidies combined with the long-term uncertainty of the marketing situation and the negative social and political legacies of the industry in the region combine to discourage any real vigour in the pursuit of this expansion. The result has been a benign neglect and a tendency to deal with the industry as an ailing part of the various national economies of the region. This has been encouraged by developments in the tourist industry (Barbados and Jamaica), bauxite–alumina (Guyana and Jamaica), oil (Trinidad and Tobago), and the growth of an import-substituting manufacturing and agroprocessing sector in all the territories of the region.

Some recognition of the quandry the governments face is reflected in the plethora of commissions, tribunals, committees of inquiry, etc. that have been established to examine the industry, or certain aspects of it, and to make recommendations. It is also reflected in the recent divestment policies introduced by the Seaga administration in Jamaica, where Tate and Lyle Ltd, the TNC that had controlled the bulk of that country's industry, has been contracted to resuscitate the industry. Although the issue has not been forcefully raised in any of the many official inquiries, one question that has emerged perennially is whether or not the single-minded use of the industry's resources to produce sucrose for consumption overseas is the best use of such a vast amount of the region's resources. In all the countries, diversification policies have been introduced. This has taken the form of introducing other crops on sugar lands; production of nontraditional products from sugar, e.g., high-test molasses and animal feeds; and the greater utilization of by-products, e.g., bagasse. The question of diversification is very much at the forefront of this inquiry and, in this sense, if no other, the study hopes to break new ground in the regional assessment of its resources devoted to sugar production. (For a discussion of the development of the industry in Guyana see Thomas (1984a,b).)

Technology and End Use: The Concept of Sweetener

The traditional view of sugar, and the one that dominates the popular consciousness in the Caribbean, is that it is an agent used to sweeten foods, beverages, etc. But sugar has other properties besides its sweetness that, if not appreciated by the average household, are clearly recognizable to that large section of its end users that makes up the industrial market for sugar. Sugar, for example, is not only sweet but it is also a food in itself, and as a food it is highly esteemed because it is nontoxic, although its consumption has been linked to dental caries, obesity, etc. The importance of these other characteristics of sugar is drawn out when sugar is placed in the wider context of its end uses. It is from this context, therefore, that high-fructose corn syrup (HFCS) has also to be evaluated. But first, the major categories of sweeteners that are produced will be discussed.

Very briefly, there are two major categories of sweeteners, namely natural caloric sweeteners and synthetic sweeteners. The former is usually subdivided into two further categories: the readily accessible carbohydrate-based sweeteners, which are most commonly used and are all calorie rich and in which sucrose dominates; and other exotic natural products with sweetening properties whose potential has not been fully exploited and whose commercialization remains limited. The schema below indicates these categories with a few pertinent remarks where appropriate. Later in the text the ones of particular interest to the study will be amplified.

Natural Caloric Sweeteners

Carbohydrate-Based Sources Readily Available

Sucrose (mainly cane and sugar beet). As far as white sugar is concerned, these two are indistinguishable but only cane sugar can be processed as brown sugar, domestic syrup, or treacle. Treacle is a by-product of the industry with about 50% sugar and is used to prepare alcohol, citric acid, yeast, animal feeds, etc.

Lactose (a disaccharide containing galactose and glucose obtained from cheese whey).

Polyhydric Alcohols (reaction of hydrogen on sugars and includes sorbitol prepared from dextrose, maltitol prepared from maltose, and xylitol prepared from wood waste). These are used mainly in soft ice creams and are thought to cause less tooth decay. Xylitol is suspected of being carcinogenic.

Starch Hydrolysates. Glucose syrups derived from starch, which contains dextrose (D-glucose) and other higher saccharides.

Fructose (the while crystalline reducing sugar that occurs naturally in fruit and flowers). Because it is metabolized differently from sucrose, it has been accepted as a diabetic sugar.

HFCS or Isoglucose (to be studied in greater detail).

Other Exotic Natural Sources

Stevioside (extracted from the leaves of *Stevia rebaudiana*).

Morellin (extracted from the serendipity berry).

Thaumatin (extracted from a West African berry).

Glycoprotein (Miraculin) (extracted from the red berry of West Africa).

Licorice.

Synthetic Sweeteners

Saccharin (isolated in 1879 and under suspicion of being carcinogenic). Its sale has been prohibited in some countries. In the U.S. it was reinstated by Congress despite a ruling of the Federal Drug Administration against it. It is the most widely used synthetic sweetener. It is also the cheapest.

Cyclamate (30–80 times sweeter than sucrose). This product has been prohibited from sale because of being carcinogenic.

Aspartame. This is the closest in terms of taste of sugar of the available artifical sweeteners. It has been approved for general distribution in the U.S. and Canada and is expected to be in Western Europe soon. It is available as tabletop sweetener and is used in processed foods and beverages. It will be discussed in more detail later.

Trichlorogalactosucrose (TGS) (a chemical modification of sucrose, to be studied in detail later).

The heavy industrial use of sugar has drawn more and more attention to the various properties or characteristics of available sweeteners. From discussions with persons in the industry it seems clear that whatever propaganda or advertisement may be put out on the properties of any particular sweetener, sucrose is still the standard from which all other sweeteners are measured. The principal qualities of cane and beet sugar (sucrose) sweeteners and those of HFCS or isoglucose are

Cane and beet sugar (sucrose) qualities	High-fructose corn syrup qualities
— Good taste	— High sweetness
— Good bulking agent	— High fermentability
— Good diluent and carrier	— High humectancy
— High and ready water solubility	— A water white colour that is readily blendable with other foods
— Good preserving agent	
— Colourless	— A clean nonmasking taste
— Chemically and microbiologically pure	— A favourable viscosity when compared with other sugars and syrups as shown in Table 4
— Nontoxic	

(continued)

Cane and beet sugar (sucrose) qualities	High-fructose corn syrup qualities
— Energy giving — Good digestibility — Rapid and total fermentability — Good storage ability — Good flavour — Its crystalline structure makes it suitable for home uses	— On a weight basis its osmotic pressure makes it a good conservator of food because there is a lower development of bacteria, yeast, and fungi without special additives — Increases moisture content of foods and lowers the freezing point, which is important in some industries, e.g., ice cream — Its sweetness has a synergetic effect on the total sweetness of food so that a 50:50 solution of HFCS and sucrose has a higher sweetness than the addition of both products — It enhances the flavour of food, particularly fruit — It is nontoxic, readily digestible, and nutritious

Table 4. Viscosity of HFCS and other sweeteners.[a]

Product	Centipoises
HFCS[b]	150
Saccharose (71 Brix)	360
Saccharose (66 Brix)	120
Dextrose	130
Invert sugar (70%)	130–150
Glucose syrup (64 DE)	500

Source: Crott (1982a,b).

[a] Viscosity measures the property of a fluid that resists the force tending to cause it to flow.

[b] Refers to 42% HFCS. Note that this product contains 71% total solids.

There are disadvantages in sucrose that will be examined later, but these refer primarily to its suitability as a chemical feedstock and not as a food. All competitive sweeteners, therefore, have to measure up to the standards set by sucrose or they are unlikely to penetrate the sweetener market in a significant way. Thus, many of the high-intensity sweeteners (e.g., saccharin), which are favoured because of their low calories, have, apart from possible carcinogenic effects, a taste and texture in the mouth that discourage their widespread use. The product that is being studied here, however, has an array of characteristics or properties that makes it a formidable competitor to sucrose.

There are three major limitations of HFCS that inhibit both its industrial and its household uses and pose technological challenges that are now being vigorously pursued. The first of these is that HFCS is a liquid sweetener. Its liquid state limits the uses to which it can be put when compared to crystalline sucrose. Thus, for example, although it can be readily used in beverages, it is not as acceptable as sugar when used as a tabletop sweetener in households. Its liquid state, however, generally inhibits its applications, but there are some manufacturing areas in which its liquid state may well constitute an advantage or be immaterial to the producer (Table 4). Thus, in the dairying and soft drinks manufacturing sectors its liquid state facilitates the use of automated liquid systems in factories. Sucrose when used in these sectors has to be converted to a liquid state. This factor as will be shown later plays an important role in determining the character of the market penetration achieved by HFCS.

The second limitation is that HFCS has to be stored at 27–36° C to prevent coloration and undesirable changes in fluidity that would impede the ease of its handling, pouring, and pumping. Again, like the previous limitation, this does not mean that this property cannot favour its use in certain industrial applications. The fact that it is subject to colour changes when heated beyond certain temperatures helps in baked products where colour changes can enhance the appearance and the appeal of the product.

The third limitation of HFCS is that it is not easily or cheaply produced in a crystalline form. A crystalline form has been manufactured, but this process is far too costly to be commercially viable yet. Resources already committed to the industry and those planned for the next 5 years or so are all premised on the continued production and use of liquid HFCS, even though the search for a cheap crystalline form goes on.

Low-Calorie, High-Intensity Sweeteners

It would be useful at this stage to offer some observations on the low-calorie, high-intensity sweeteners. First, the stimulus for the development of these sweeteners derives principally from the worldwide concern about excessive calorie and particularly carbohydrate intake, which can lead to obesity and which seems to have accompanied increasing industrialization, incomes, and access to food; the urbanization of many countries; and changes in cultural and food consumption patterns that favour the fast-foods industry. Second, the major limitations of existing products are that they have tastes and other physical attributes, e.g., texture in the mouth, and the absence of bulk (because the sweeteners are of high intensity) that do not make them readily acceptable as a substitute for sucrose. They also frequently do not interact well with other foods and more often than not are thought of as being possibly carcinogenic. With the exception of saccharin, and possibly Aspartame, these products are also costly and presently uncompetitive. The industry's rule of thumb is that a high-intensity sweetener has to be at least 50 times as sweet as sucrose to break even. Table 5 gives a broad indication of sweetness factors, calorie value/sweet-

Table 5. Selected comparisons of high-intensity sweeteners.

	Sweetness factor	Calorie value/ sweetness	Sweetness quality	Relative cost per unit of sweetness
Sucrose	1.0	4.0	Very good	300
HFCS	1 +	4.0	Very good	280
Glucose	0.7	5.7	Good	300
Fructose	1.2	3.3	Fruity	1000
Invert sugar	1.0	4.0	Very good	300
Sorbitol	0.5	8.0	Bland	1200
Xylitol	1.0	4.0	Bland	4200
Saccharin	300	0.0	Sweet/metallic/bitter	10
Cyclamate	30–120	0.0	Clean/sweet	70
Aspartame	180	0.0	Sweet/slightly lingering	420
Acesulpham K	150	0.0	Sweet/chemical/bitter	—
Talin	3000	0.0	Sweet/lingering	350
TGS	600 +	0.0	Like sucrose	—

Source: Nicol (1980) and Crott (1982a,b).

ness ratios, sweetness quality, and relative cost per unit of sweetness derived from recent studies.

As pointed out in the introduction, one high-intensity, artificial (synthetic) sweetener that has been recently developed and is claimed not to be carcinogenic and whose sweetness profile has been found in consumer surveys to be acceptable is Aspartame. This product is produced by G.D. Searle, the major pharmaceutical corporation headquartered in Illinois, U.S. The product has been described as follows (Bylinsky 1982:28):

> Its principal characteristics make Aspartame seem almost too good to be true; it is generally judged to taste about as good as sugar, it has only a tiny fraction of sugar's calories, and it has the stamp of approval from the FDA which now deems Aspartame 'absolutely safe'. Armed with those qualities, Aspartame is now emerging as a formidable opponent of both sugar, abhorrent to the diet-conscious, and of saccharin, which leaves an unpleasant and lingering aftertaste and which has lingering around it the persistent fear that it is carcinogenic.

In evaluating this statement it should be noted that the industry's view (attributed to H.R. Roberts, Vice President, Science and Technology, National Soft Drink Association (see Price 1982:3)) of an ideal alternative to sugar is that it

> . . .should be significantly sweeter than sugar with a pleasant taste and no aftertaste. . .chemically and physically stable, colourless and odorless and water soluble. It should be compatible with a broad spectrum of food applications, preferably with existing processing techniques and equipment. Finally, it should be competitive in cost and free of adverse health effects.

The author of the statement goes on to point out that of the many alternatives currently available, Aspartame heads the list.

Aspartame is 200 times sweeter than sucrose. Its cost of production per unit of sweetness is substantially in excess of sugar, depending on the price of sugar, and it is about 30 times the cost of the equivalent produced by saccharin. It is believed that these cost differences will be overlooked if the health hazards truly disappear. Many feel confident about Aspartame's health claims because it is produced from a combination of two amino acids that occur widely in common foods: aspartic acid and phenylalanine. Attached to the Aspartame molecule is a methyl ester, "a type of structure that represents a natural flavouring agent of fruits and vegetables" (Bylinsky 1982:30). (Like saccharin, Aspartame's sweetening power is supposed to be an "accidental" discovery. It is attributed to a chemist working with amino acids in Searle's laboratories (J.M. Schlatter). Phenylalanine is linked to a genetic disease (phenylketonuria).) On the other hand, saccharin is a petroleum-based product. It is not surprising, therefore, that in the space of a few years sales of Aspartame by G.D. Searle have grown from US$73 million in 1980 to an estimated value of US$750 million in 1984.

Although this study does not treat the artificial sweeteners as a topic in itself, the development of products like Aspartame adds to the threats facing sugar. It is important to bear in mind that despite its adverse taste, and health concerns voiced about it, the sugar equivalent of saccharin in U.S. consumption is also up, from 5 lb/person in 1971 to more than 7 lb/person (1 lb = 0.454 kg). Saccharin's sales currently total about US$3 billion. Thus, while HFCS is rapidly substituting for sucrose, the consumption of all forms of high-calorie sweeteners is under pressure from low-calorie and synthetic sweeteners. The threat of these sweeteners, however, does not and indeed cannot remove the dangers of a continued displacement of sucrose by HFCS, even if the total market for nutritive sweeteners contracts is in the industrialized countries.

The Global Sweetener Market

In recent years the global sweetener market has shown, despite its annual and crop year variations, a broad pattern of declining per capita consumption of sweeteners in the developed countries and an increasing per capita consumption in the developing countries. The increases in consumption in the developing countries have been accompanied, however, by strong efforts toward their own individual self-sufficiency in sugar production, so that increased consumption is not fully reflected in increased international trade. The overall growth of world production/consumption of sweeteners has been about 2–2.5% per year since 1975.

The general industry rule of thumb is that when per capita consumption is below 15 kg/year the household consumer market for sugar dominates consumption, and when it is more than 50 kg/year the industrial food-processing sectors predominate. Between 15 and 50 kg per capita consumption of sugar the balance progressively shifts in favour of the industrial market as consumption increases. Table 6 shows the global picture of the per capita consumption of sugar by continent. Fifty countries have a per capita consumption of less than 15 kg/year. The bulk of the countries (87) fall within the range of 15–50 kg/year. Most of the Caribbean territories fall within this group, although quite high on the scale. Thus, in Trinidad and Tobago and Guyana per capita consumption is currently around 44–46 kg of domestic sugar alone. If sugar imported in foodstuffs is added the figure may well exceed 50 kg, thereby forming a major category of exception to this general rule. The reason for this type of exception is of course the high domestic availability of sugar combined with local sales at more-or-less subsidized prices aimed at reducing the cost of living burden of sugar consumption on lower-income households. In other words, domestically consumed sugar in the region is subsidized and this subsidization encourages its relative overconsumption.

The world supply of centrifugal sugar averaged more than 98 × 10^6 t for the years 1982–84, but consumption averaged about 93 × 10^6 t, indicating an oversupply over the last 3 years. The data in Table 7 indicate the demand/supply levels by various regions, and the role of the traditional suppliers and demanders can clearly be observed as well as the regional balances between output and consumption that give rise to trade in sugar. The emergence of West Europe as a

Table 6. Per capita sugar consumption (number of countries by continent).

	<15 kg	15–50 kg	>50 kg
Europe	1	19	2
America	1	28	7
Asia and Oceania	19	19	4
Africa	29	21	1

Source: Nicol (1980).

Table 7. World supply and demand of centrifugal sugar, raw value, 1980–84 (10^6 t).

	Supply					Demand				
	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
Total Africa[a]	5.96	6.84	11.17	10.04	11.08	6.71	6.90	8.51	8.59	8.72
Cuba	6.81	7.93	8.04	7.46	8.06	—	—	—	—	—
Total Central America	12.70	13.70	14.31	14.06	14.67	5.03	5.08	5.49	5.29	5.48
U.S.	5.31	5.79	5.42	5.21	5.37	9.33	9.07	8.31	8.07	7.65
Total North America	5.40	5.89	5.55	5.35	5.50	10.34	10.01	9.25	9.08	8.68
Brazil	8.27	8.73	8.94	9.56	9.32	6.26	5.87	6.10	5.91	6.05
Total South America	13.31	13.64	14.06	14.41	14.12	10.70	10.44	10.43	10.27	10.51
India	4.53	5.99	9.13	8.45	6.48	5.04	5.39	6.71	7.18	8.36
Total Asia and Oceania[a]	18.57	21.91	24.17	25.47	24.37	22.14	22.69	24.68	25.96	27.77
Total East Europe	11.97	11.80	12.91	14.47	13.47	17.71	17.67	18.47	18.75	18.93
EEC	13.55	15.48	15.51	12.30	12.72	10.97	10.59	10.69	10.53	10.45
Total West Europe	16.67	18.84	19.47	16.59	16.66	15.07	14.74	14.89	14.66	14.63
World total	84.60	92.24	101.43	96.81	95.81	87.71	87.54	91.72	92.60	94.71

Sources: International Organization for Standardization Statistical Bulletin, Landell Mills Commodity Bulletins (Sugar).

[a] After 1982, Oceania data added to Africa not Asia.

major sugar-producing region with a large excess supply is probably the single most important characteristic of these data. In all the years for which the data are presented (1980–84), output of sugar substantially exceeded demand in West Europe thereby turning that region into a major beet sugar exporting region, but it is still a critical element in the world's import market for cane sugar. The data also show that the traditional imbalance between domestic output and demand in North America, while being reduced, nevertheless remains substantial. For the years 1980–84, output in North America averaged about 58% of consumption, so that North America continues to be an important sugar-importing region. The same is true for East Europe where, despite increases in output, supply is still considerably less than consumption. The regions of Africa, Asia, and Oceania show smaller imbalances, with the exception of Australia, which remains a major sugar-exporting country.

The output levels for sugar in 1980–84 indicated in Table 8 compare with a world output of HFCS of about 2.8×10^6 t in 1980, 3.6×10^6 t in 1981, 4.1×10^6 t in 1982, 4.7×10^6 t in 1983, and 5.3×10^6 t in 1984. Of this amount the U.S. has produced 2.0, 2.5, 2.9, 3.4, and 3.8×10^6 t in respective years. Table 8 contains projections to 1990 of world consumption of sweeteners by major categories. The data there suggest that by 1990, 81.3% of sweetener consumption will be in the form of centrifugal sugar and 9.2% will remain as noncentrifugal. Noncaloric sweetener consumption will be 1.3% and starch-based sweeteners 8.2% of the total, which equals 11.6×10^6 t out of a total world consumption of sweeteners of 141.4×10^6 t in 1990. A word of caution, however, is needed at this stage. The nature of the sweetener industry and market is such that projections of output and consumption are invariably hazardous and it is not surprising how often in the past estimates have varied from actual performances. Consequently, these projections, as indeed the several others that will be presented in this study, should be handled with due care.

Although this study is not concerned with a detailed analysis of the world's sugar market, certain features of it are important for forming the background to the assessment of both the HFCS industry and the sucrochemical industry. The first of these is that international trade accounts for only 20–25% of world sugar output. There are six major importers: China, USSR, Japan, EEC, Canada, and the U.S. Of the total traded sugar only about one-tenth to one-sixth of it is traded on the open market. This makes the free market a residual one with most of the burden of adjustment to world surpluses and deficits falling on a small percentage of sugar production. The remainder of the sugar trade is marketed under special bilateral and regional marketing arrangements. Of the total sugar traded as much as 90% is derived from cane.

Second, the world market for sugar is characterized by periods of oversupply and undersupply leading to wide fluctuations in the prices and quantities

Table 8. World sweetener consumption: projection 1990 (10^6 t, raw sugar equivalent).

	1950	1960	1970	1980	1990
Centrifugal sugar	31.0	48.3	72.1	91.0	115.0
Noncentrifugal sugar	7.1	8.4	10.2	12.0	13.0
Starch-based sweeteners	1.9	2.4	3.6	7.5	11.6
Noncaloric sweeteners	0.4	0.4	1.3	1.5	1.8
Total	40.4	59.5	87.2	112.0	141.4

Source: Earley (1980).

of traded sugar in the open free market. Thus, for 18 out of the last 38 crop years (1945–83) world production of centrifugal sugar has exceeded world demand. Stocks of sugar have fluctuated between one-fifth to nearly two-fifths of annual consumption. A time series of world sugar output and ending stocks as a percentage of consumption is shown in Table 9, and in Table 10 the movements in prices are revealed. (It should be noted that the data in Table 9 are presented on a crop-year basis.) The data in Table 10 highlight the considerable instability of sugar prices. In the years since 1950, five definite sugar cycles have been identified, all of them with the characteristic boom in prices followed by rapid declines. These five cycles are 1951–55, 1956–61, 1962–68, 1969–77, and 1978 onward.

Because so much sugar is marketed by special agreements, the role of political factors and government policy has been foremost in influencing price behaviour. In an effort to impose some order and harmony in these arrangements, a seventh International Sugar Agreement (ISA) was signed in 1977. This expired in 1984 despite several meetings and sugar conferences that were convened in an effort to construct a new agreement to go into effect when the existing ISA expired. At the moment, therefore, apart from purely administrative arrangements there is no international agreement on sugar pricing, stocks, quotas, etc.

The basic weaknesses of the past agreement were, first, the procedures for establishing basic export tonnages had resulted in quotas that were larger than the outlets for sugar so that few exporting countries have suffered significant export restrictions under its provisions. Agreements that work on export quota schemes tempt producers to reach a high level of performance in the years on which quotas are to be calculated to enhance their quota in the scheme. They are also tempted to enter into the agreement with their stocks as low as possible to reduce their obligations to carry stocks under the agreement. Second, member countries had conveniently ignored their obligations to restrict imports from nonmembers and as a consequence this latter group of countries has found no real difficulties in exporting their output. Third, the nonparticipation of the EEC, which as noted earlier has become under their domestic sugar support

Table 9. World sugar production and stocks consumption ratio by crop year.

Crop year beginning in September	Total output (10^6 t)	Ending stocks as a percentage of consumption
1972	75.1	22.1
1973	80.0	21.6
1974	78.5	24.5
1975	81.7	26.5
1976	86.3	30.3
1977	92.5	34.6
1978	91.1	34.2
1979	84.4	26.4
1980	87.7	27.4
1981	100.2	35.5
1982	97.4	38.6
1983	96.3	39.3

Sources: USDA, Economic Research Service, Sugar and Sweetener Outlook and Situation (various issues). The recent years are based on estimates by C. Czarnikow Ltd in Sugar Review, and Landell Mills Commodity Bulletins (Sugar).

Table 10. Raw sugar spot prices (U.S. cents/lb).[a]

Year	World price
1972	7.43
1973	9.61
1974	29.99
1975	20.49
1976	11.58
1977	8.11
1978	7.82
1979	9.74
1980	29.01
1981	17.33
1982	8.50
1983	8.58

[a] 1 lb = 0.454 kg.

schemes a major producer, importer, and now exporter of sugar, has inevitably curtailed the effectiveness of the present ISA.

The EEC's sugar policies have not only affected trade in sucrose but they have also restricted the development of HFCS production in that region in favour of domestic beet cultivation, so much is the power of the beet farmers' lobby. Although the EEC subsidizes its own sugar production and consequently exports, it imports cane sugar under the special protective arrangements of the EEC–ACP Sugar Protocol of the Lome Convention, a development out of the previous colonial relationships of Europe in Africa, the Caribbean, and the Pacific. The net effect of all these considerations is that the ISA has played a negligible role in regulating sugar prices, certainly when compared with counterpart schemes for cocoa, coffee, and rubber. As will be discussed more fully later, the EEC's efforts to support the sugar beet industry of Europe is also the major factor discouraging its expansion of HFCS production (Crott 1982a,b).

Because of the importance of political considerations in the operations of the world's sugar market, the range of countries that at present trade in sugar compounds the difficulties of a common approach to an orderly international sugar regime. Significant sugar exports now range from countries highly dependent on sugar in terms of foreign currency earnings and where most of the sugar produced is exported (Cuba, Dominican Republic, Guyana), through major producers that have a high internal consumption so that only a relatively small proportion of total output is exported (Brazil, India), to a third group of major producers and exporters for whom sugar plays a relatively minor role in their economies (EEC, Australia). These differences have yielded very different views on what a new ISA should be like. The developing countries would ideally favour a cost plus pricing mechanism adjusted for inflation of prices. Importers favour schemes that minimize subsidies to inefficient producers while making the market orderly. All previous agreements were based on supply regulated mechanisms in the form of export quotas. A majority of countries still favour this. The EEC, however, favours a stockholding scheme and it is on this issue that negotiations deadlocked.

Although the U.S. is not a major exporter of sugar, it is a major producer and importer. The abandonment of the U.S. Sugar Act in 1974, which came hard on the heels of the end of the CSA, greatly affected the traditional protected marketing of Caribbean sugar. Since then the U.S. has generally pursued a policy of high sugar prices — the effect of which has been to encourage, contrary to the EEC, the development of the HFCS industry while encouraging the U.S. production of beet and cane sugar. In May 1982, the U.S. resorted to quarterly country-by-country import quotas for sugar and raised the market stabilization price of sugar to 19.88 cents/lb, up from 19.0 cents/lb. This was done to protect domestic producers from the threat of a global surplus of sugar production and its effect on prices as, for the year 1982, the forecast average for the raw sugar spot price was only 9.1 cents/lb. As was noted earlier, this was revised to an annual quota in October 1982 with the result that the U.S. is not a very attractive preferential market for sugar. All these developments have resulted in a trend of declining U.S. imports of sugar. Currently, imports are expected to stabilize around $2-2.5 \times 10^6$ t, about half the levels of the late 1970s.

At present, therefore, it can be safely said that imported sugars are the effective, direct competitor of HFCS, particularly in the U.S. Because, as will be shown, HFCS costs less to produce than either beet or cane sugar in the U.S., the impact of its growth will be felt on world trade to a far greater extent than elsewhere. Furthermore, the probability exists that any future interruptions to the expansion and growth of HFCS in the U.S. will lead to the introduction of government measures directed first and foremost at restricting imports. This, therefore, makes HFCS production in the U.S. a strongly entrenched industry.

In conclusion, the fact that sugar is an agricultural commodity produced by entirely different methods, in widely different climates, and under widely different social systems and work conditions in both developed and developing countries will always produce a tendency toward great uncertainty and complexity in its marketing. It is this feature that has created an increasingly stronger tendency among the developing countries to sustain regional groupings to promote their interests. The African–Pacific–Caribbean joint approach to the EEC, enshrined in the Lome Convention, is one example of this. Another is the formation of the Group of Latin American and Caribbean Sugar Exporting Countries (GEPLACEA) in 1974. This latter grouping affects about 43–48% of total world sugar exports. The regional body is, however, primarily a consultative, coordinating, and information-pooling agency for member countries with reference to the production and marketing under fair and remunerative prices of the sugar and molasses that they produce.

Chapter 2

Innovation in a Mature Industry: The Case of HFCS

Development of HFCS Technology

The food industry has traditionally used microorganisms derived from natural sources to produce new foods, to increase the palatability of existing ones, and to alter others so that they could be kept longer. Examples of these processes are the brewing of ale, beer, etc., the making of alcohol, the production of dairy foods, and the production of food flavourings, e.g., soy sauce. It was also known that starch could be converted into a sweetener by an acid process (hydrolysis) and this process was commercially utilized on the basis of potato starch in the U.S. as early as 1850. In 1866, corn sugar or dextrose was being produced in limited quantities in the U.S. These traditional uses of enzymes and yeasts were, however, limited in their applications.

Thus, in the case of the corn industry, wet millers knew as early as the 1800s the process for converting D-glucose (an aldose) to D-fructose (a ketose). This process is known as isomerization and explains why in Europe HFCS goes by the name of isoglucose. The process known then consisted of treating glucose with an alkaline catalyst at a high pH. The technology was limited in its applications because of two major circumstances associated with this process. One was that in the process of conversion excessive by-products were produced, which tended to cause dark colours and to develop off-flavours. This point underscores the significance of the properties other than sweetness in determining the industrial potential of sweeteners that have been referred to in the previous chapter. Unfortunately, technically these undesired effects could have been removed, but their removal was far too expensive to make the product economical. The other limitation was that the process was crude and really consisted of nonspecific and uncontrollable reactions that made its industrial uses very limited.

In spite of this, research on sugar isomerization continued, but much of the research was being done on the metabolism of carbohydrates in bacterial and animal cells and was concentrated on 5-carbon sugars (pentoses) instead of the 6-carbon sugars like D-glucose. By the 1950s, however, a significant discovery was made. It was found that free monosaccharides outside the cell would undergo ketolisomerization in the presence of a proper enzyme. The proper enzyme discovered was *xylose isomerase*. This discovery was, however, not made within the sweetener industry or the food industry but by biological and medical scientists who were studying the role of sugars in the metabolism of the biological system. The significance of this work was not quickly appreciated by the corn wet-milling industries until the publication by Hockster and Watson (1953, 1954) on xylose isomerase was "accidentally" noted by Elder, a research director in CPC International. (This observation was made by Casey (1976) on the basis of a personal communication from Elder. For the early history of the development of HFCS see Bode (1967) and Casey (1976).)

Further research continued and was directed toward finding a glucose isomerase that could convert glucose to fructose through the necessary rearrangement of the molecular structure of glucose. The main difference of the two sugars is that glucose has 6 carbons and xylose has 5. Laboratory research by Marshall and Kooi revealed that the enzyme prepared from *Pseudomonas hydrophilia*, which was described in the literature as a specific xylose isomerase, also functioned as a glucose isomerase in the conversion of D-glucose to D-fructose. This discovery was of particular importance because D-fructose is much sweeter than D-glucose. Limitations on its application, however, in industrial processes existed and the corn industry did not adopt the new scientific discovery, although a patent was taken out by the U.S. firm CPC, on the Marshall and Kooi process (U.S. patent number 2950228, issued 23 August 1960).

Research in the general area continued in the 1960s, but the centre for this research shifted to Japan. Here also the initial focus was biological, and much of the work was conducted in research institutes and not industry. It was only later that the commercial food orientation came to the forefront and industry began to take note. In 1965, the Japanese researcher J. Sato reported that filamentous bacteria, *Streptomyces*, produced glucose isomerase. Together with Tsumura, a Japanese patent (number 17640 issued on 7 October 1966) was taken out on the *Streptomyces (Actinomyces)* species. At about the same time Y. Takasaki, another Japanese researcher working at the Fermentation Research Insitute of Japan, published an article on the commercialization of this process. The article stressed the suitability of the process to the wet-milling industry for the production of HFCS. Again CPC bought out exclusive rights to utilize the enzyme for production. The U.S. patent to Takasaki was given in 1971 (patent number 3616221).

Despite these favourable developments, the corn wet millers were not particularly receptive, ignoring the process that they believed was too expensive. In part this reflected their focus on commercial feasibility, but it also reflected the slow response to technical innovations that frequently occurs in a mature industry. The main high-cost factor was attributed to the cost of enzymes. At the time, soluble enzymes were used in a batch reaction process and then discarded. A momentous breakthrough, however, in the field of enzyme technology was at hand, as a new technique of enzyme immobilization had been developed that could permit the indefinite use of enzymes in the process of isomerization. The possibility of the repeated reuse of enzymes would mean considerably lower costs of enzyme production.

It was not until 1967, however, that commercial U.S. production of HFCS began. This was done on licence from Takasaki and the Japanese government. The first production contained 15% fructose. This was later raised to 30% and within a year to 42% HFCS. The process in operation was the older batch system using a soluble glucose isomerase. The emerging technology of enzyme immobilization was not used. The 42% HFCS produced in 1968 was the first generation of genuine HFCS sweeteners. By 1972, however, a continuous process using immobilized enzymes was introduced at the Clinton Corn Processing Industry.

Ten years, therefore, elapsed between the discovery of the glucose isomerase and its significant commercial utilization. Two key factors were apparent in the timing of its more general development in U.S. industry. The first was the result of legal action taken between CPC International and Standard Brands Inc., which resulted in the removal of basic patent coverage for the isomerization of glucose to fructose in 1975 and cleared the way for its more general industrial use. The second factor was the tremendous boom in sugar prices of 1974, which at one stage peaked at 66 cents/lb. This served as a strong incentive for industrial users to switch to HFCS, and much of the industry's present capacity was built on decisions made during this period, the industry being, as will be explained more fully later, very sensitive to the price of competitive sweeteners. The collapse of sugar prices after 1975 depressed the industry particularly as overcapacity became evident. By 1980–81, however, there was a partial recovery of prices accompanied by all-round technological improvements that made the industry more and more competitive and its business outlook optimistic.

Although these issues will be discussed in detail in Chapter 4, it is pertinent to note here that in the production of HFCS, by-product recovery (corn oil, corn feeds, and cornmeal) has ranged from 40 to 60% per bushel corn cost. The prices of these products had also strengthened during the period 1980–81, leading to a favourable impact on the development of the industry.

Enzymatic conversion of dextrose into fructose reaches equilibrium at 50% conversion, which is a 50 : 50 liquid mixture of D-glucose and D-fructose, so that the HFCS produced at 42% fructose was the commercially practical limit while having the same sweetness as liquid sugar.

In the industry, there has naturally been a strong incentive to improve on this conversion rate and as a result of a new fractionation technology that involves the chromotographic separation of fructose from dextrose by means of ion exhange resins a 55% variety HFCS was produced in 1978. This is now in widespread commercial production. With the new fractionation technology, it is theoretically possible to produce up to 100% fructose-bearing syrup, but, to date, the 55% and to a far lesser extent a 90% product are the only ones commercially produced. The 55% product is 10% sweeter than sucrose, but the 90% product is one to one and a half times as sweet as sucrose and is largely used in health foods and other such specialty areas. The 55% product is produced by blending the 90% product with the 42% product.

The breakthroughs in enzyme production have been of the greatest significance to the industry. In the U.S. this is one of the fastest growing, "new" technology industries. Currently, there are more than a dozen different microbial producers of glucose isomerase, with six of these being commercially produced (Crott 1982a,b). There are also a wide variety of techniques used in the immobilizing of the enzymes and several types of reactors are used in the industry. These reactors have been classified as batch, packed bed, continuous flow stirred, and ultracentrifugation membranes. The most commonly used is the packed bed (Crott 1982a,b). Although the enzyme glucose isomerase is now being genetically engineered, it is expensive as it requires a long complex system for purification. New techniques directed at "customizing" enzymes are being developed. In these, the aim is to take a low-cost enzyme and transform it chemically and physically so that it behaves like the more expensive one.

Although the bottlenecks of enzyme production have been overcome and are still being improved on, the major remaining hurdle is the commercial crystallization of HFCS. If this is done on a cost-effective basis, it would become a direct competitor to table sugar. Cetus Corporation (a California-based bioengineering laboratory) has joined with Standard Oil Co. of California to develop a process for the crystallization of fructose. The technique used so far is to convert dextrose to fructose in a manner different from that currently used in the production of HFCS, but the process is so far not cost competitive with sugar in all its uses. This will be discussed in more detail in the next section.

A schematic outline of the processes involved in the production of HFCS is shown in Figures 1 and 2. In Fig. 1, the production of dextrose syrup from corn, which is the substrate for conversion of fructose, is shown. Having obtained the

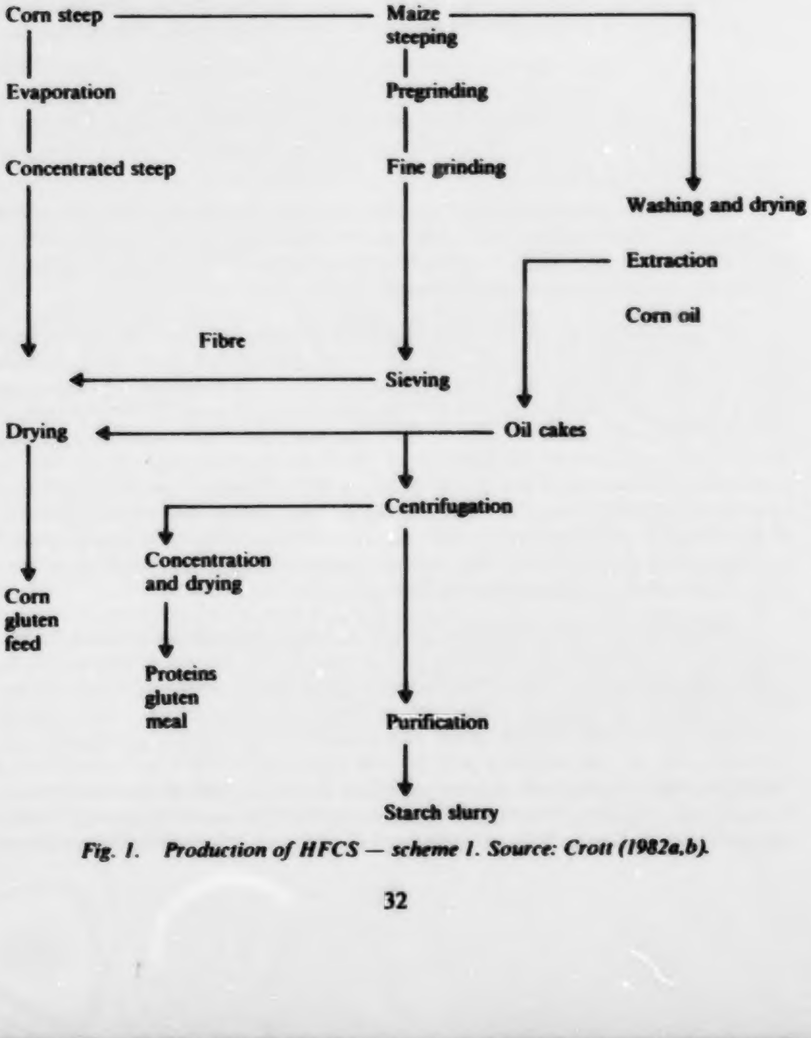
Corn steep
Maize steeping
Evaporation
Pregrinding
Concentrated steep
Fine grinding
Washing and drying
Extraction
Corn oil
Fibre
Sieving
Drying
Oil cakes
Centrifugation
Concentration and drying
Corn gluten feed
Proteins gluten meal
Purification
Starch slurry

Fig. 1. Production of HFCS — scheme 1. Source: Crott (1982a,b).

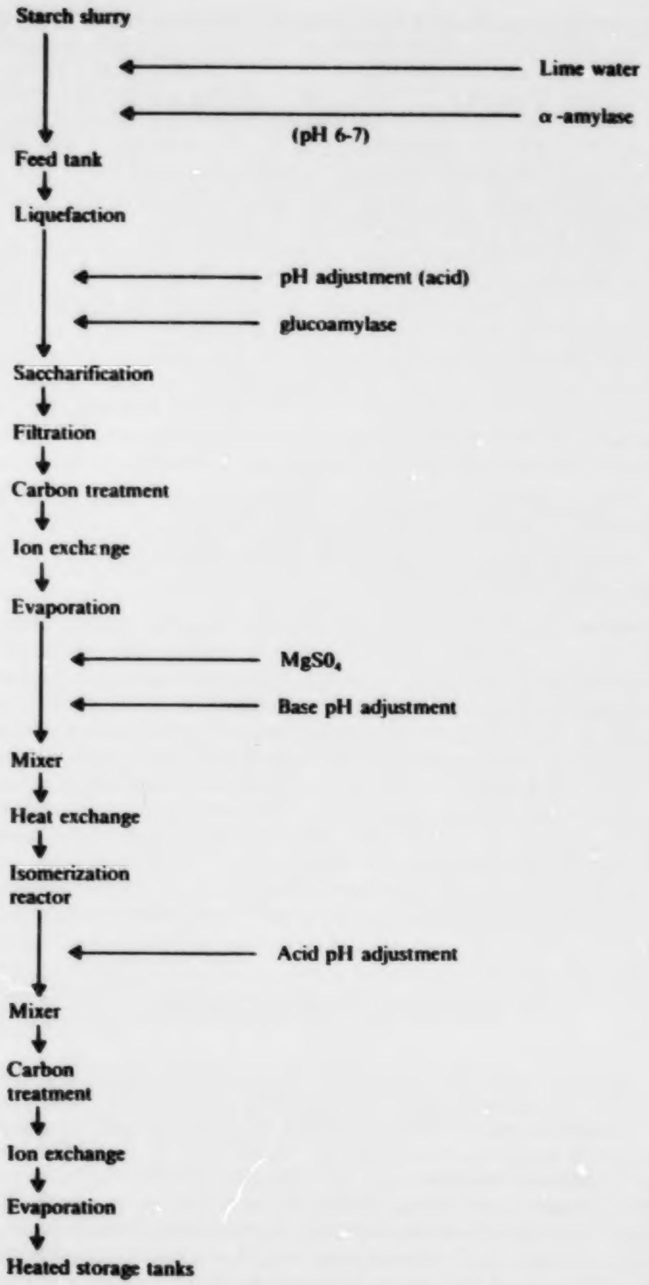
Starch slurry
Lime water
α -amylase
(pH 6-7)
Feed tank
Liquefaction
pH adjustment (acid)
glucoamylase
Saccharification
Filtration
Carbon treatment
Ion exchange
Evaporation
$MgSO_4$
Base pH adjustment
Mixer
Heat exchange
Isomerization reactor
Acid pH adjustment
Mixer
Carbon treatment
Ion exchange
Evaporation
Heated storage tanks

Fig. 2. Production of HFCS — scheme 2. Source: Crott (1982a,b).

substrate, starch slurry, the isoglucose process is shown in Fig. 2. In the process in Fig. 2, the starch slurry, which has about one-third dry solids, is liquefied by bacterial α-amylase and heated to about 80–110°C. This process is a continuous one with the pH raised to 6–7. After a short cooling period (up to 60°C) the liquefied starch is saccharified by application of glucoamylase and the adjustment of the pH to 4.0–4.5. The holding time here is 24–90 hours. The result is a saccharified starch of 94–96% dextrose, measured on a dry basis. This is then de-colourized with carbon and the calcium ions that were added for liquefaction are removed to prevent their deactivation of the isomerase enzyme. In some processes this deionizing step is omitted where the α-amylases used are appropriate. The refined dextrose is then concentrated (to about 40–45% solids) and is placed in a mixer tank where various salts are added and the pH again adjusted to 7.0–8.5 depending on the type of enzyme used and the reactor type. At this stage, it is the dextrose content of the substrate that determines the yield of the finished product. The only reaction of the glucose isomerase introduced after this stage is to convert dextrose to fructose. This is possible because the continuous process using immobilized glucose isomerase forms a very minimal by-product as the contact time between enzyme and substrate is short.

After isomerization is completed and about one-half of the dextrose converted to fructose the solution is refined, the pH adjusted to 4.0–4.5, and the product concentrated to 71% dry solids by evaporation. In the case of 55% HFCS, dry solids constitute 77%.

Further details on reactor design and enzyme usage are not necessary at this juncture, but the interested reader can follow the summary given by Crott (1982a,b). The important point to note is that as indicated earlier there is a mixture of reactor designs in use. The preference noted for the packed-bed type is because in this type of reactor the concentration of active glucose is higher and contact time between enzymes and substrate shorter. This helps to reduce the costs of HFCS production. Similarly, the effectiveness of the enzymes depends on a number of parameters: contact time between substrate and enzyme, pH, temperature, oxygen, size of particles, purity of syrup, presence of metal ions, concentration of syrup, degree of microbial infection of the stream, etc. As Crott points out "it is here that the 'craftsmanship' and experience of the user is of importance to select and control the best possible mix of the parameters" (Crott 1982a,b).

Analytical Observations

A number of important analytical observations emerge from this brief survey of the development of HFCS technology. The first of these is the wide range of disciplines that have converged to make the innovation possible and later ensured its application to large-scale production. To begin with, there has been the traditional chemical interest in the role of microorganisms in food production, which has been transformed by the new developments in enzyme technology. There has also been the role of medical and biological research in the metabolism of sugars in the human body, which was instrumental in the isolation of the enzyme and the present understanding of the process of isomerization. In addition, there has also been the work of those scientists who saw the commercial possibilities of what was a primarily scientific discovery and played an important role in moving the discovery from a scientific stage to the technological application stage.

The convergence of these various disciplines and the merging of basic scientific research and technological innovation have not, however, been easy or straightforward. Long lags existed between the development of the basic isomerization process and its industrial application. This signals the *crucial role of interdisciplinary awareness in successful technological development and science and technology (S&T) planning*. In the literature on technical innovation there is presumed to be a substantial lag (usually 8–15 years) between the time technical innovation is generated and it is used as an innovation. This lag varies from product to product with chemical/pharmaceutical developments falling in the mid range. In the case of HFCS, if 1952–53 is treated as the pivotal year for the breakthrough discovery (Casey 1976), then it took 7 years of basic research and a further 7 years of technology advancement and 2 years for industry to commercialize the results; a total of just over a decade and a half.

A second observation is that although government and private corporations have played a role in the development of HFCS (the Japanese government through its Fermentation Institute and the many corn-milling corporations in the U.S., Europe, and Japan), much of the critical work was done in research institutions. This factor may have helped determine the lag in the application of these scientific advances in the cornstarch industry, but an important point is that a crucial feature of S&T planning should certainly be the creative networking of what might appear at first to be independent and often unrelated institutions, enterprises, and agencies.

A third observation is that the long established and "mature" nature of the corn wet-milling industry must certainly have hampered its flexibility and creativity in dealing with the technical changes outlined here. Several factors suggest that this was so. One is that although the starch industry had always supported enzyme research, this has been confined to hydrolases or degradative types. The breakthrough inherent in the possibilities of a different class of enzymes that could rearrange the sugar molecule D-glucose was not appreciated by the industry until Elder's "accidential" noting of the work of Hockster and Watson. Another factor is that even after this was appreciated it took more than a decade, up until 1965, for U.S. corn wet millers to show interest in the discoveries. Casey (1976) severely criticized the corn wet-milling industries for these delays. Finally, even after enzymes were in use, the industry was slow to adopt the immobilization techniques that were being developed. As Casey (1976:30) observes

> . . .the failure of industrial carbohydrate technologists to recognize at an early date the technical advantages and economic impact of enzyme immobilization technology was a major oversight, which can be ascribed to poor knowledge exchange between scientific disciplines.

The immobilization of creativity and innovation associated with mature industries leads to long intervals in innovation, and these long intervals in turn further immobilize these industries, creating an unhealthy spiral of technological conservatism.

A fourth important analytical observation is the truly international character of the development of HFCS technology. Early work in the U.S. was followed by a period of concentrated development of research into isomerization in Japan supported by government and universities. The long list of publications emanating from Japan[1] between the years 1961–69 is good testimony to the work done there. Later however, the major applications were made in the U.S. The reason why the Japanese, noted for their quick spotting and implementation of a profitable technical breakthrough, did not appear to seize the opportunities afforded by their own researchers in their breakthroughs in HFCS technology is that as far as the resource configuration of Japan goes, that country remains relatively indifferent to the pattern of development of sweetener technology. It has no large-scale sugar beet industry or corn production, and both the traditional production of sucrose and HFCS are highly raw-material intensive. The leading role played in the development of the industry by U.S. corporations, therefore, in large measure reflects the preponderant global role of U.S. corn producers.

A fifth observation is that from the inception there were always three major technical hurdles that had to be overcome if HFCS was to be a commercial success: to produce a better than 42% product, to produce and utilize enzymes efficiently, and to crystallize the final product. The first of these technical hurdles was overcome by the development of fractionation technology, which is the separation of a mixture, usually of chemically related or otherwise similar components, into fractions of different properties. This technology has been applied to crystallization and distillation of mixtures making use of fractionating columns.

The second of the technical hurdles was overcome through the rapid development of the enzyme industry. Indeed the HFCS industry combines two industries, the corn wet millers and the enzymes producers. Some corn wet millers do, of course, produce their own enzymes. The U.S. market for microbial enzymes is at present estimated at nearly US$200 million, and the world market at approximately US$400 million. Discussions with persons knowledgeable in the industry suggest that the general rule is an annual growth in the industry of about 15%.

These enzymes are not only used in HFCS production but also in gasohol, waste treatment, blood tests, etc. When sucrochemicals are examined in Part II of this study this subject will be returned to because the fermentation processes are important to the production of sucrochemicals. The expansion of R&D and production capacity in enzymes is reflected in a significant fall in the cost of enzymes in the production of HFCS. As noted in Chapter 4, in 1972 the cost of enzymes accounted for 16% of the total cost of HFCS, but currently it is under 5%. At present, as many as 100 organisms have been patented as isomerase producers even though as indicated earlier only about six are widely used, with firms utilizing not only different organisms but different immobilization methods, as each has different properties.

Despite all these gains the view is that "most scientists believe another breakthrough may be required in enzyme genetics or in the discovery of more heat stable varieties before additional savings can be made" (Nordland 1980:18).

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[1] The list of Japanese publications includes: Tsumara and Sato (1961a,b); Takasaki and Tanabe (1962a,b); Nakate and Yoshimura (1963, 1964); Yamanaka (1963a,b); Takasaki (1966); Tsumura et al. (1967); Takasaki et al. (1969).

This may be true for some industries, however, as far as HFCS is concerned, the cost savings that can be expected will only be marginal. It is important, however, not to dismiss the impact of progressive improvements of an incremental sort in enzyme technology and isomerizing conditions.

One U.S. firm, Cetus Corporation, has used a new route based on olefins conversion. The olefin, a halide ion, and hydrogen peroxide are catalyzed by an enzyme to alkene halohydrin, which another enzyme then converts to the oxide, releasing the oxide for recycling. A variety of oxides can be produced with only small modifications. The halide ion is inexpensive and recyclable. This process may be upgraded with recombinant-DNA techniques focusing on modifying the useful enzyme to produce more enzymes or the enzyme's genetic coding may be transplanted to a different organism more suited to upward industrial scaling.

With reference to the third bottleneck, the following quote from the then General Manager of the Sweeteners Division of Tate and Lyle Ltd is apt (Nicol 1980:73):

> If HFCS could be dried to a granular solid and stabilized economically, sucrose could be very seriously threatened. The technical problem is not easy, but the prize is substantial, so it must be assumed that considerable research is in progress in this area.

Discussions with persons in the industry have always elicited the view that this research is well advanced and that before very long the commercialization of a crystalline process would be forthcoming. If this were to happen the threat to sucrose would indeed be substantial, but even without it, as will be shown in the following chapters, the threat that already exists is formidable indeed.

The final observation that I would like to make stems from the relation of corn of HFCS. As already suggested, the production of HFCS yields important by-products that have a critical bearing on the economics of HFCS production. In addition to this, corn can be used to produce not only HFCS but an entirely different product, ethanol, using the same fermentation process. In turn, this product can be used as either a chemical feedstock or, as is more likely, a gasolene extender. Already sugarcane has been used in this way, most notably in the Brazilian gasohol program. This alternative use of corn is possible within more or less the same plant design and production processes. Indeed, the flexibility even extends into the yielding of the same by-products (corn oil, corn feed, and cornmeal) as in HFCS production. This flexibility of plant switching gives ethanol produced by corn a strategic competitive flexibility when compared to the use of sugarcane, thereby increasing the threat to the stability of a sucrose industry based on cane sugar.

In the U.S. the view is that ethanol has the most "immediate potential" of all the renewable resources to cope with the present energy crises. From this point of view as Nordland has observed: "corn and grain sorghum [are] the most attractive feedstock in terms of availability and economics" (Nordland 1980:18). The U.S. government has indeed afforded it limited encouragement as a fuel extender. Current U.S. production is about 60 × 10^6 gal (227.12 × 10^6 L) and it is projected that output of this product could range from 300–900 × 10^6 gal (1135.62–3406.86 × 10^6 L) this year. Two U.S. corn producers had switched capacity to ethanol production in 1980 in the face of "overcapacity" in HFCS production, namely, Archer-Daniels-Midland in Cedar Rapids and CPC International in Pekin, Illinois, USA. In conclusion, it should be noted that the U.S. consumes on average over 300 × 10^6 t of gasolene annually. To replace 10% of this would be equivalent to 2.5 times the entire annual consumption of ethanol on a 95% alcohol basis.

Chapter 3

Structure of the HFCS Industry

World Structure

High-fructose corn syrup is commercially produced in significant quantities in the U.S., Japan, Canada, and the EEC, with minor levels of output achieved in several non-EEC countries and in a few countries of Asia, Latin America, and Africa. Total world output is currently estimated at the end of 1984 as being 5.3 × 10^6 t. This total is somewhat higher than earlier estimates projected by industry sources, reflecting the rapid development of the industry. Table 11 presents data on estimates of global production of HFCS for the period 1980–85. These data show that the total world output in 1980 of 2.8 × 10^6 t is estimated to double by the end of 1985. This exceptionally high rate of growth has occurred in all producing areas.

The data also show that the U.S. has been the overwhelmingly dominant producer of HFCS. Not only did it pioneer commercial production, but that country produced about 75% of total world output in 1980. Since then, despite increased output from other countries, its relative share of world output has not declined, as it is estimated to be almost three-quarters by the end of 1985. As far back as 1974, less than 5% of HFCS output was of the 55% variety (second-generation HFCS). By the end of 1984, installed capacity had led to this second-generation product accounting for more than one-half the total HFCS market. World output of 90% HFCS, however, remains negligible with only the U.S. producing a small amount (about 100 000 t).

In the following sections the structure of the industry will be examined in some detail in terms of the major producing areas and markets and projections will be made concerning future output. Here it would be useful to complete the global picture by noting in a very preliminary way the amount of total output being projected for the world. Table 12 summarizes a few of the projections currently available and the dates they were made on.

Earley's (1980:42–49) projections, which go as far as 1989–90, have already been surpassed and so have GATT-FLY's (1980) estimates. My own estimates are based on current capacity and output levels together with announced capacity changes up to the end of 1984 and I have allowed for a lag of 2–3 years between the announcement of planned changes in output and actual changes. The main advantage of this estimate along with Vuilleumier's and the Landell Mills Commodity Studies estimates are their recency. The variation in estimates

Table 11. World production of HFCS, 1980-85 (10^3 t, dry basis).

Country/region	1980	1981	1982	1983	1984	1985
USA	2045	2540	2900	3385	3800	4100
Canada	42	85	110	140	165	190
Total North America	2087	2625	3010	3525	3965	4290
EEC	185	192	187	185	185	185
Other West Europe	60	85	85	95	110	120
Total West Europe	245	277	272	280	295	305
Total East Europe	15	30	45	75	80	100
Japan	365	525	590	625	660	690
South Korea	16	55	92	95	115	140
Other Asia	1	5	8	10	40	100
Total Asia	382	585	690	730	815	930
Total Latin America	40	45	50	65	80	110
Total Africa	—	—	—	—	20	40
World total	2769	3562	4067	4675	5255	5775

Source: Landell Mills Commodities Studies (1979-84).

Table 12. Projections of world HFCS production (10^6 t).

	1984-85	1989-90
Earley (1980)	4.0	5.1
Vuilleumier (1981a,b)	5.6	—
Vuilleumier (1983)	5.2	—
GATT-Fly (1980)	4.0	—
Hagelberg and Ahlfeld (1981)	4.5	5.5
Koutras and Greditor (1981)	5.2	—
Thomas (1984)	5.6	—
Landell Mills Commodities Studies (1979-84)	5.7	—

presented in the table is, however, considerable, ranging from 4.0-5.7 × 10^6 t. The fact, however, that output recorded and actual capacity changes announced in the U.S. exceed some of the early estimates suggests that the higher estimates are the more reliable. Two final points should be observed in this preliminary look at global production. The first, which is not self-evident from the tables, is that almost all the world's output is sold in the internal markets of the producing countries with the exception of some movements from Canada to the U.S. Apart from this, international trade in HFCS products is negligible. The second, is that the industry has been going through such rapid and dramatic changes that estimation is difficult. The lowest estimates for 1984-85 were made the earliest (1980). Since then, events have overtaken the assumptions of the various authors and raise the issue of how far ahead projections can be made accurately.

United States Industry

The U.S. is the dominant country in the world's sweetener industry. It is a major producer of all the principal sweeteners: cane sugar, beet sugar, corn syrup, dextrose, noncaloric sweeteners, as well as HFCS. It is also a major importer of sweeteners — particularly cane sugar from developing countries. As a consequence, developments within the U.S. have the profoundest significance for future developments on a world scale. As already noted, the U.S. is by far the world's largest producer of HFCS. The raw material base on which its output capacity has been built up is the domestic availability of corn. The U.S. is the world's largest producer of corn. Its current output of about 170 × 10^6 t represents about half of the world's output of corn, whereas exports of corn from the U.S. alone account for 75% of world trade in this commodity. More than three-quarters of the corn produced, however, has so far been used principally as animal feed to sustain the meat and dairy industries.

In Table 13, estimates of nutritive sweetener deliveries in the U.S. are presented for the years 1975–82, along with projections to 1985. These data indicate that between 1975 and 1982 the consumption of sucrose has shown some recovery after 1975 but that by 1980 the consumption level had returned to that of 1975. Since then, the trend has been downward.

The consumption of dextrose is small with no definite trend, whereas the consumption of HFCS has grown dramatically. Increases, to a far lesser extent, have been recorded in the consumption of corn syrup. The result of these developments has been that overall corn-sweetener deliveries have risen rapidly relative to cane and beet sugar deliveries. In 1975, corn sweetener deliveries amount to 24% of total deliveries, and currently these averaged 40% of total deliveries. For the same period, the overall growth in sweetener deliveries was just over 10%.

The striking growth of HFCS consumption is readily observed from an analysis of Tables 12 and 14. In 1975, for example, per capita consumption of HFCS was 2.3 kg, by 1985 it is estimated at 14.1 kg, which is an increase by a factor of more than 6. The decline in the per capita consumption of dextrose and sucrose should also be noted in Table 14. Corn syrup deliveries have shown a very small increase in per capita consumption, rising from 8.0 kg in 1975 to 8.3 kg in 1985. As a result, total per capita corn sweeteners consumption shows a growth from 12.6 kg in 1975 to 24.4 kg in 1985. Total sweetener consumption, meanwhile, was 53.6 kg per capita in 1975 and had risen by only 7% to 57.4 kg in 1985.

From the projections in both Tables 13 and 14, the method of calculation used by the source should be noted. The author assumes a roughly 4% annual decline in sucrose consumption over the period because of corn sweetener substitution. As far as corn syrup and dextrose are concerned a marginal, 0.2%, annual rate of increase has been assumed. HFCS growth rates are, however, substantial, with a 15% increase projected for 1983–84 and a 10% increase projected in 1985. These are all calculated on the basis of the author's 1981 estimates of deliveries. On this basis, corn sweeteners should account for 48% of the total sweetener market in 1985, with HFCS alone accounting for 30% of the market. Meanwhile, sucrose consumption is expected to decline substantially, averaging only about one-half the sweetener market by 1985. Although projections of sweetener deliveries and consumption are particularly hazardous, Vuilleumier's estimates have not been very far out. The values within parentheses in Table 13 indicate the actual figures for the years 1980–83, and no serious discrepancies exist in the author's projections of HFCS output except for a tendency to underestimate output slightly.

The complex nature of the sweetener industry and its high degree of susceptibility to output variations based on price changes, weather, political, and other circumstances are too well known for the difficulties of forecasting to

Table 13. USA: estimated nutritive sweetener deliveries (1975–85) (10^3 t, dry matter).

Year (a)	Sucrose (b)	Corn syrup (c)	HFCS (d)	Dextrose (e)	Total corn (f) (Col. c+d+e)	Total sweetener (g) (Col. b+f)	Corn % (h)
1975	8734	1714	482	499	2695	11429	24
1976	9235	1728	715	499	2942	12177	24
1977	9410	1759	942	413	3114	12524	25
1978	9232	1796	1221	385	3402	12634	27
1979	9119	1819	1543	390	3752	12871	29
1980[a]	8545 (8600)	1882 (1852)	1905 (2045)	398	4185 (4295)	12730 (12895)	33 (33)
1981[a]	8203 (8375)	1920 (1909)	2286 (2540)	406 (364)	4612 (4813)	12815 (13188)	36 (35)
1982[a]	7875 (8100)	1958 (2050)	2743 (2900)	414 (485)	5115 (5435)	12990 (13535)	39 (42)
1983[a]	7560	1997	3154 (3385)	422	5573	13133	42
1984	7258	2037	3628	431	6096	13354	46
1985	6968	2078	3990	439	6507	13475	48

Source: Vuilleumier (1981a,b) and USDA, Sugar Market Statistics (various issues).

[a] Figures within parentheses are revised estimates of actual output for 1980–83 obtained from recent publications.

Table 14. USA: estimated nutritive sweetener deliveries (1975–85) (kg/capita, dry matter).

Year (a)	Sucrose (b)	Corn syrup (c)	HFCS (d)	Dextrose (e)	Total corn (f) (Col. c+d+e)	Total sweetener (g) (Col. b+f)	Corn % (h)
1975	41.0	8.0	2.3	2.3	12.6	53.6	24
1976	43.0	8.0	3.3	2.3	13.6	56.6	24
1977	43.5	8.1	4.3	1.9	14.3	57.8	25
1978	42.3	8.2	5.6	1.8	15.6	57.9	27
1979	41.4	8.3	7.0	1.8	17.1	58.5	29
1980	38.0	6.2	8.7	1.6	18.5	56.5	33
1981	36.0	8.3	10.5	1.6	20.4	56.7	36
1982	33.7	8.0	12.5	1.9	22.4	56.1	40
1983	33.0	8.1	13.0	1.9	23.0	56.0	41
1984	33.0	8.2	13.6	1.9	23.7	56.7	42
1985	33.0	8.3	14.1	2.0	24.4	57.4	43

Source: Vuilleumier (1981a,b, 1983) and USDA, Sugar Market Statistics (various issues).

be underestimated. Indeed at the time of writing this report (second quarter of 1985), the price of sugar had not yet recovered and had reached unbelievable lows. The glut in world sugar supplies is also being projected as continuing and it is being suggested in some quarters that if these conditions prevail overcapacity may well emerge in the HFCS industry converting the cautious projections of Tables 13 and 14 into unduly optimistic forecasts. Although this may be so, the evidence of undercapacity is very much the issue now particularly in light of important decisions favourable to HFCS expansion that have been announced. The most important of these is approval for 100% conversion to this sweetener announced by Pepsi Cola and Coca Cola. If this were to be fully implemented sales to the beverages market alone could be as much as 2.75–3 × 10^6 t of HFCS.

The data presented in Table 15 show the estimated output of HFCS by product. These reflect the expectation that second-generation HFCS, i.e., the 55% variety, will become the major product of the HFCS industry replacing the 42% variety. As the data show, the 55% product accounted for only 11% of the total output of the industry in 1978, but, by 1985, this is projected to be as high as 59%.

Data on the industrial deliveries of HFCS and sugar by-product categories are presented in Table 16. These data reveal a number of interesting points. First, the major sales of HFCS are clearly in the beverages, baking, and canning industries. Of these major markets, the beverage industry's is by far the largest — accounting for a possible 62% of all sales and 57% of the total beverage market for sweeteners in 1983. The recent decisions referred to by the two major beverages producers will no doubt be followed by other beverage companies, and this will have a major impact on the development of the HFCS market. Indeed when it is considered that Coca Cola has only changed its formula three times in its history, the far-reaching consequences of this decision cannot be easily overestimated because of the importance of the beverage market. Second, although sales in canning and processed foods together account for far less than one-third of the sales in the beverages sector, the proportion going to HFCS is quite high, 66 and 57%, respectively. Third, the smallest share of the market for HFCS is in the area of confections. Here the failure to develop a crystalline product has been the decisive factor.

The data in Table 17 show the structure of the U.S. sucrose market for 1979–81. From these data it can be observed that less than 40% of the sucrose is used for nonindustrial purposes, with industrial uses ranging between 61 and 63% of total sucrose. The saying "sugar in the home, HFCS in industry," reflects the fact that HFCS threatens the industrial market. The structure of this market is, therefore, particularly relevant to this inquiry. The data in this table show clearly that the major industrial markets are, first, beverages, followed by baking and cereals, and confectionery. The market for canned foods, ice cream and dairy products, and miscellaneous foods follows. This market structure for

Table 15. USA: estimated HFCS deliveries by product: 1978, 1980, 1982, 1985 (10^3 t, dry matter).

Product type	1978		1980		1982		1985	
	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%
42%	1085	89	1293	68	1588	50	1636	41
55%	136	11	612	32	1588	50	2354	59
Total	1221	100	1905	100	3176	100	3990	100

Source: Vuilleumier (1981a,b, 1983).

Table 16. USA: industrial sugar and HFCS deliveries by market (1980–81) (10^3 t, dry matter).

	Sugar				HFCS				HFCS as percentage of sweetener market			
	1980	1981 (estimate)	1982	1983	1980	1981 (estimate)	1982	1983	1980	1981 (estimate)	1982 (estimate)	1983 (estimate)
Beverages	2160	1960	1632	1540	990	1302	1995	2100	31	40	55	57
Baking	1340	1135	1305	1331	470	391	420	431	26	25	24	24
Canning	590	485	230	205	410	305	363	396	41	43	61	66
Dairy products	450	432	405	400	180	176	185	189	29	29	31	32
Processed foods	540	396	205	175	120	101	193	230	18	20	48	57
Confections	930	816	934	962	10	11	20	21	1	1	1	1
Total industrial	6010	5244	4711	4613	2180	2286	3176	3367	36	31	40	42

Source: Vuilleumier (1981a,b) and Smith (1982).

Table 17. USA: structure of the sucrose market (%).

Industrial	Actual use		
	1979	1980	1981
Beverage	22.9	22.8	20.1
Canned foods	8.1	6.2	5.3
Ice cream and dairy products	4.9	4.7	5.0
Baking and cereals	11.2	14.1	14.2
Miscellaneous processed foods	6.0	5.7	6.3
Confectionery	8.2	9.8	10.7
Total	61.3	63.3	61.6
Nonindustrial	38.7	36.7	38.4

Source: Barry and Gilbert (1981) and USDA (1981, 1982).

sucrose can be profitably compared with the possible theoretical penetration of HFCS into these markets. Table 18 presents three such estimates, one by Rivero (1980) and two others by Vuilleumier (1981a,b, 1983).

Although there are some differences all the estimates agree on the complete switching over of the beverages industry to the use of HFCS products. Rivero projects a 100% switch over and Vuilleumier a 90% switch over. Rivero also sees a total substitution in the canned goods industry but Vuilleumier limited his first estimate to 60% and later revised this to 70–75%. The next major market segments are dairy products and miscellaneous products with Rivero giving half of these to HFCS and Vuilleumier 30 and 40% respectively, in his first estimate, later revising these to 35 and 60–65%, respectively. Both authors give baking and cereals a 25% penetration. In all the estimates, the confectionery market is the least likely to be affected — reinforcing the importance of the technical hurdle of HFCS being a noncrystalline product. The projections, however, vary significantly with Rivero giving an estimate of 20% and Vuilleumier only 5%.

In Table 19, estimates of HFCS deliveries by market are given. In these estimates, the predominance of the beverages market and the limited role of the confectionery market are once again highlighted. In Table 20, the actual figures

Table 18. USA: HFCS — estimates of long-term theoretical penetration by market (%).

Product	Rivero 1980	Vuilleumier 1982	Vuilleumier 1983
Beverages	100	90	90
Canned foods	100	60	70–75
Dairy products	50	30	35
Miscellaneous processed foods	50	40	60–65
Baking and cereals	25	25	25
Confections	20	5	5

Source: Rivero (1980) and Vuilleumier (1981a,b, 1983).

Table 19. USA: estimated HFCS deliveries by market 1980–85 (10^3 t, dry matter).

	1980	1981	1982	1983	1984	1985
Beverages	967	1302	1676	2000	2354	2669
Baking	385	391	423	440	497	502
Canning	288	305	328	366	413	432
Dairy products	168	176	187	198	204	211
Processed foods	88	101	116	130	138	147
Confections	9	11	13	20	22	29
Total	1905	2286	2743	3154	3628	3990

Source: McKeany-Flavell Co., Inc. projections with adjustments, as quoted in Vuilleumier (1981a,b).

Table 20. USA: market shares for HFCS (%).

Major market	Estimated market share				Actual 1980
	1980	1983	1985	1985	
Beverages — carbonated and noncarbonated	51.0	62	67	62	45
Baking	20.0	13	12	12	22
Canning	15.0	12	11	12	19
Dairy products	9.0	6	5	5	8
Processed foods including jams, preserves	4.5	7	4	8	6
Confections	0.5	1	1	1	0.5

Source: USDA statistics and Vuilleumier (1981a,b, 1983).

for 1980 are given alongside Vuilleumier's estimate of production in 1980, made during 1980, and in 1983, made during 1983, along with his two estimates of market shares made in 1981 and 1983 for the year 1985. These reveal variations, but the data support the ranking of markets given by Vuilleumier even though there are differences between the actual and estimated percentages, the most significant being in the case of beverages and canning.

Before leaving the issue of the market distribution of HFCS, a few observations picked up from interviews and discussions with persons in the industry are worth noting. One of these is the point made repeatedly that the growth of the confectionery market for HFCS is limited by the failure to produce a crystalline fructose at a competitive price. The moisture affinity of the liquid product impairs its use in the confectionery industry, although some producers of confectionery are using limited quantities of HFCS. In the market for baked goods it would appear from discussions that most of the growth so far has been by way of a substitution for dextrose, so that the growth of the HFCS here affects principally the corn-sweetener category. In the canned-foods industry, a major problem that exists is the browning of the product from use of HFCS, and this has so far restricted its use. Finally, in the dairy industry, the growth of HFCS has met with the obstacle of its tendency to lower the freezing point of ice cream. All these technical hurdles indicated here can, theoretically, be overcome. The issue, however, is whether this can be done at a competitive price. Indications are that the industry is confident of soon being able to overcome these obstacles and evidence of this is said to be given by the production capacity expansions already announced by the industry.

Finally, the data in Table 21 show that within the U.S. 11 firms, with 17 plants predominantly located in the Midwest, are responsible for its output of HFCS. The largest of these are Archer Daniels Midland and A.E. Staley (with about one-quarter of the total capacity each). These are followed by Cargill and Clinton. Together, these four firms account for nearly three-quarters of the total market. If CPC International (10%) and Hubinga (5%) are added, these six firms account for 90% of the market. A point of some significance, which will be taken up later in the study, is that the HFCS-producing firms in the U.S. also have major investments in cane and beet sugar along with maize, and food products such as soybean, flour, etc. In summary, the following can be noted:

(a) The U.S. is the world's largest producer of HFCS, with capacity projected to rise at a rapid rate over the next 5–10 years.

Table 21. USA: expansion of 42% and 55% HFCS capacity by firms (dry lb/year (× 10⁶)).[a]

Company	Actual capacity		Estimated change						Estimated capacity			
									Vuilleumier (1981a,b)		Vuilleumier (1983)	
	1980 (42%)	1980 (55%)	1981 (42%)	1981 (55%)	1982 (42%)	1982 (55%)	1983 (42%)	1983 (55%)	1983 (42%)	1983 (55%)	1983 (42%)	1983 (55%)
American maize products	250	—	(75)	325	—	—	—	—	175	325	142	269
Amstar	250	—	—	—	—	200	—	—	250	200	150	200
Anheuser-Busch	75	—	—	—	—	—	—	—	75	—	—	—
Archer Daniels Midland	1100	400	(100)	850	—	—	—	—	1000	1250	1000	1250
CPC International	310	—	235	—	245	100	—	—	790	100	760	100
Cargill	260	—	(50)	260	160	280	—	—	370	540	400	620
Clinton	670	300	(150)	135	—	—	—	—	520	435	520	450
Great Western	30	70	—	—	—	—	80	320	110	390	30	70
Hubinger	320	170	—	—	—	—	—	—	320	170	320	170
Holly Sugar	100	—	—	—	—	—	—	—	100	—	100	—
Staley (A.E.) Manufacturing	770	620	—	570	—	—	—	460	770	1650	895	1475
Total	4135	1560	(140)	2140	405	580	80	780	4480	5060	4317	4604
Cumulative total	4135	1560	3995	3710	4400	4280	4480	5060	—	—	—	—
Estimated demand	2992	1388	3182	2142	3385	3305	3600	5100	—	—	—	—
Excess capacity (%)[b]	38	12	26	72	30	30	24	(1)	—	—	—	—

Note: 1 lb = 0.454 kg.

Source: Vuilleumier (1980, 1981a,b, 1983) and Barry and Gilbert (1981).

[a] Figures within parentheses signify capacity converted to 55% HFCS.

[b] As a percentage of demand. Roughly 14% is required to allow for seasonal fluctuations.

(b) Most of the expanded output will be in the area of second-generation HFCS, or the 55% variety.

(c) The major market for HFCS will be beverages, followed by baking and canned goods, the smallest market will be confectionery.

(d) The growth of market shares will depend on certain technological developments in crystallization, but already the theoretical possibility of penetrating the sucrose market is considerable.

(e) The growth of HFCS occurs in the context of a static or declining growth in the overall sweetener market in the U.S.

(f) The U.S. firms in the industry have a highly oligopolistic structure. They are also multiproduct firms, in particular producing significant quantities of other sweetener substitutes.

Canadian Industry

The Canadian markets for sweeteners generally and HFCS in particular are far smaller than those of the U.S. Unlike the U.S., however, Canada's sugar prices reflect world prices so that no special protection is afforded HFCS production. Currently, less than 200 000 t of HFCS is being produced. Like the U.S., the market for corn sweeteners has grown rapidly between 1975 and 1984. In the latter year, it accounted for about one-third of the total sweetener market as compared with more than 40% in the U.S. Canada does not produce dextrose, and all of its requirements are imported from the U.S. It produces corn syrup, and the estimates show that by the end of 1984 its lead over HFCS would be reversed. Data on a comparable basis to that used in presenting the U.S. industry are shown in Tables 22 and 23. Canadian production of HFCS only began in 1979. Like the U.S., per capita consumption of sucrose has been falling, from 43.5 kg per capita in 1975 to 34.4 kg per capita in 1984. The level of per capita sucrose consumption in Canada is slightly above that of the U.S., but in overall sweetener consumption the U.S. is ahead.

Table 22. Canada: estimated nutritive sweetener consumption (1975–85) (10^3 t, dry matter).

Year	Sucrose	Corn syrup	HFCS	Dextrose	Total corn	Total sweetener	Corn %
1975	987	76	0	16	92	1079	8.5
1976	901	84	0	17	101	1002	10.0
1977	1039	92	0	18	110	1149	9.6
1978	1027	100	0	19	119	1146	10.4
1979	1051	108	10	18	136	1187	11.5
1980	1000	118	42	19	179	1179	15.0
1981	960	125	90 (85)	19	234	1194	19.4
1982	912	121	110 (110)	20	250	1162	21.5
1983	885	140	190 (140)	20	350	1235	28.3
1984	850	148	240	21	409	1259	32.5
1985	816	156	290	21	467	1283	36.4

Notes: Actual outputs of HFCS for 1980–83 are noted within parentheses. For 1975–80, sucrose figures F.O. Licht, corn sweetener figures McKeany-Flavell estimates. For 1980–85, sucrose figures assume a 4% annual decline because of corn sweetener penetration, corn syrup growth assumed 6% annually, dextrose growth assumed 3% annually, and HFCS figures assume a 50000 t annual increase because of capacity expansions.

Source: Vuilleumier (1981a,b).

Table 23. Canada: estimated nutritive sweetener consumption, 1975–85, (in kg/capita, dry matter).

Year	Sucrose	Corn syrup	HFCS	Dextrose	Total corn	Total sweetener	Corn %
1975	43.5	3.3	0.0	0.7	4.0	47.5	8.5
1976	39.2	3.6	0.0	0.7	4.3	43.5	10.0
1977	44.7	3.9	0.0	0.7	4.6	49.3	9.6
1978	43.8	4.3	0.0	0.7	5.0	48.8	10.4
1979	44.5	4.6	0.4	0.8	5.8	50.3	11.5
1980	41.9	4.9	1.7	0.8	7.4	49.3	15.0
1981	39.9	5.1	3.7	0.8	9.6	49.5	19.4
1982	37.4	5.0	4.5	0.8	10.3	47.7	21.5
1983	36.1	5.7	7.7	0.8	14.2	50.3	28.3
1984	34.4	6.0	9.7	0.9	16.6	51.0	32.5
1985	32.7	6.2	11.6	0.9	18.7	51.4	36.4

Source: Vuilleumier (1981a,b).

The projections in these two tables show that Canadian HFCS output should reach 290 000 t by the end of 1985 or 23% of total sweeteners consumption and 37% of industrial sweeteners consumption. Sucrose consumption is projected to fall from 81% of total sweetener consumption in 1981 to 64% by 1985. Like the U.S., the projections are based on a 4% annual decline in sucrose deliveries between 1980 and 1985, but corn syrup growth is projected here at 6% annually over the same period. HFCS capacity has been projected on the basis of an annual increase of 50 000 t to 1985, but this has not happened. Actual output in 1983 was 140 000 t, lagging 1 year behind the projected increments to annual output. Canada has tended to export some of its HFCS to the U.S. from time to time so that projections of domestic consumption do not coincide with growth of output. Because Canada does not subsidize its HFCS output to the extent that the U.S. does, it is much more susceptible to the pressures of imported sugar prices than in the case of the U.S., and this factor has undoubtedly affected the industry's expansion plans because the spot raw sugar price has been exceptionally low.

The data in Table 24 indicate that the incremental growth of second-generation HFCS between 1981 and 1985 will be greater than that of the 42% variety. This is in keeping with what is expected in this industry. The market shares of sugar consumption in Canada are also shown in Table 25. As one

Table 24. Canada: estimated HFCS production capacities (10^3 t, dry matter).

	Additional capacity expected					
	1981		1982		1985	
	42%	55%	42%	55%	42%	55%
Canada Starch						
Cardinal	59		15	12		12
Port Colborne[a]			50	51	50	51
Zymaize Company						
London	90	23		23		34
Totals	149	23	65	86	50	97
Cumulative totals	149	23	214	109	264	206

Source: Vuilleumier (1981a,b). Estimates are from public sources and Agriculture Canada.

[a] HFCS 42% and 55% production expected late 1982 with expansion potential to about 450 × 10^6 lb (1 lb = 0.454 kg). Assumes 50% distribution between 42% and 55% production for 1982 and beyond.

Table 25. Canada: estimated consumption of industrial sugar by industry and long-term penetration of HFCS (%).

Product	Consumption of industrial sugar by industry	Theoretical long-term penetration
Beverage	33	70
Baking	16	20
Processed foods	15	25
Canning	13	40
Dairy	10	20
Confections	10	5
Other	3	—

Source: Vuilleumier (1981a,b).

would expect, the ranking is similar to that of the U.S., except that the positions of miscellaneous processed foods and canning are reversed. The figures quoted in this table are all estimates and too much reliance should not be placed on their accuracy even though overall they support the trends current analysis would lead one to expect.

The long-term penetration possibility of HFCS for each of the major market segments in Canada is also shown in Table 25. Generally, this accords lower levels of penetration to HFCS in the Canadian market, as compared with those projected for the U.S. market. These figures seem principally to reflect the different levels of industrial development attained and the degree of differentiation of the sweetener markets in the two countries. The location, however, of Canada's industrial heartland in close proximity to the U.S. corn belt makes it impossible to separate the two markets fully.

In conclusion, it should be noted that two companies control the Canadian market. One of these, Zymaize, is a subsidiary of Tate and Lyle Ltd of London, England, and the other, Canada Starch, is a subsidiary of CPC International. As Canada is a net importer of sugar and corn, it follows that these TNC investments in Canadian HFCS are clearly based as much on Canada's integration and access to the U.S. corn market as to Canadian corn producers.

Japanese Industry

Because of its resource configuration, Japan is both an importer of sugar and of corn. There is no specific resource imperative leading to the development of HFCS production, even though Japanese researchers have played a key role in the technological innovations in the development of this product. The Japanese, however, have traditionally regulated their internal sugar market to subsidize beet and cane sugar growers, with the result that Japan has had, since 1965, the highest sugar price supports in the world. Not surprisingly, this has created a price differential in favour of HFCS, encouraging its expansion. Production began in 1977, leading eventually to regulations being introduced in October 1982 to control the production of each HFCS manufacturer.

The Japanese market for sweeteners is large, totaling an estimated 3.6×10^6 t in 1982, or about 25–28% of the U.S. market. Because of its high level of industrialization, the industrial demand for sugar is also high, accounting for about 60% of total consumption. Like the U.S., consumption of sucrose between

Table 26. Japan: estimated nutritive sweetener deliveries 1975–85 (10^3 t, dry matter).

Year	Sucrose	Corn syrup	HFCS		Dextrose	Total corn	Total sweetener	Corn %
			42%	55%				
1975	2725	316	–	–	120	436	3161	14
1976	2979	380	–	–	138	518	3497	15
1977	3159	353	162	–	146	661	3820	17
1978	2967	294	218	–	141	657	3624	18
1979	3130	304	251	–	144	699	3829	18
1980	2870	270	285	90	145	790	3660	22
1981	2795	270	150	300	140	860	3655	24
1982	2711	273	177	341	141	932	3643	26
1983	2630	276	208	388	142	1014	3644	28
1984	2551	279	244	441	144	1108	3659	30
1985	2475	282	285	503	145	1215	3690	33

Source: Vuilleumier (1981a,b).

Table 27. 1975–85 Japan: estimated per capita nutritive sweetener deliveries (in kilograms, dry matter).

Year	Sucrose	Corn syrup	HFCS	Dextrose	Total corn	Total sweetener	Corn %
1975	24.5	2.8	–	1.1	3.9	28.4	14
1976	26.5	3.4	–	1.2	4.6	31.1	15
1977	27.8	3.1	1.4	1.3	5.8	33.6	17
1978	25.9	2.6	1.9	1.2	5.7	31.6	18
1979	27.1	2.6	2.2	1.2	6.0	33.1	18
1980	24.6	2.3	3.2	1.2	6.7	31.3	22
1981	23.7	2.3	3.8	1.2	7.3	31.0	24
1982	22.8	2.3	4.4	1.2	7.9	30.7	26
1983	21.9	2.3	5.0	1.2	8.5	30.4	28
1984	22.1	2.3	5.7	1.2	9.2	30.3	38
1985	30.3	2.3	6.5	1.2	10.0	30.3	33

Source: Vuilleumier (1981a,b).

Table 28. 1981–82 Japan: estimated annual HFCS production capacities and actual production levels (tonnes wet including 25% moisture).

		Production capacities		Production levels[a]	
Manufacturer	Location	HFCS-42%	HFCS-55%	HFCS-42%	HFCS-55%
Showa Sangyo	Ibaraki-ken	42000	42000	19000	27400
Gunei Kagaku	Gunma-ken	24000	18000	10400	14900
Gunei Kagaku	Hokkaido	18000	18000	3600	10400
Sanmatsu Kogyo	Chiba-ken	96000	78000	57000	53000
Sanmatsu Kogyo	Fukuoka-ken	30000	18000	27000	25000
Aito	Aichi-ken	96000	—	39000	—
Nihon Corn Starch	Aichi-ken	96000	108000	39600	38200
Sanwa Denpun Kogyo	Nara-ken	72000	72000	44800	48600
Nihon Denpun Kogyo	Kagoshima-ken	36000	42000	23300	23300
Kato Kagaku	Aichi-ken	120000	108000	54500	54500
Nihon Shokuhin Kako	Shizuoka-ken	72000	96000	59500	34000
Others		103000	60000	24800	47100
Total		805000	660000	402500	376400

Sources: Toshoku America, Inc. New York and Tokyo, and Vuilleumier (1983).

[a] Production levels for fiscal year 1981 are assumed to be equal to consumption.

Table 29. 1981–82 Japan: estimated markets for sugar and HFCS (%).

	Sugar	HFCS
Beverages	22	62
Confectionery	22	—
Consumer use (household)	20	—
Baking	11	10
Processed foods	14	7
Dairy products	5	7
Other	6	14

Source: Toshoku America, Inc., and Vuilleumier (1983).

[a] Includes soft drinks, milk, juices.

1975 and 1983 has not grown significantly. The expansion of HFCS consumption has, however, been estimated to reach a total of between 700 and 800 000 t during the current year. Overall, corn-sweetener consumption has risen from 14% of total sweetener consumption in 1975 to an estimated 33% by the end of 1985, with HFCS consumption rising from nil to nearly 75% of the corn sweeteners consumed in the current year.

Despite its high levels of industrialization, per capita consumption of sucrose in Japan is estimated at about 20 kg in 1985 or about two-thirds of the U.S. figure. Total per capita sweetener consumption is also estimated at just over 30 kg for the year 1985, that is just over half the U.S. consumption. Not surprisingly, therefore, HFCS consumption per capita remains relatively small at about 6.5 kg for 1985, or less than one-half estimated consumption in the U.S. Relevant data are shown in Tables 26 and 27, which also contain projections for 1985. These are based on the following assumptions:

(a) A 4.3% annual decline in sucrose consumption as compared with 4% in the U.S.;

(b) Corn syrup and dextrose deliveries are projected on a 1% annual growth over the period, as compared with 2% for the U.S.; and

(c) HFCS is projected on an annual 15% increase as compared with staggered U.S. increases of 20% over 1981–82, 15% for 1983–84, and 10% for 1985.

In the projections for Japan, Vuilleumier allocates HFCS in the ratio of 60 : 40 for the 55% and 42% varieties. He projects the total corn sweetener market to increase its share to 33% of the overall total, with HFCS accounting for roughly 20% of the overall total.

Production capacity of HFCS by manufacturer and by type of product is shown in Table 28. These data indicate a less oligopolistic market structure than in the U.S. The largest manufacturer has about 16% of total capacity with the next largest having about 14%. Following on these, the next two firms together account for about 23% of capacity, making the four leading firms responsible for 53% of production capacity. This can be compared with the four leading firms in the U.S., which account for about 75% of U.S. capacity. The data in this table also reveal that more than one-half of the present capacity is in 42% HFCS, but increases in capacity will, as with Canada and the U.S., favour the 55% product.

In Table 29, the market distribution of HFCS in Japan is shown along with sugar. Following on previous patterns exhibited in North America, the largest market segment is the beverages sector, accounting for roughly two-thirds of the market share. Baking is next with 10% and processed foods and dairy products at 7% each. The miscellaneous category "other" accounts for 14% of the total market for HFCS. Its confectionery and household use is recorded at zero.

EEC Industry

Given its size and degree of industrialization, one would have expected the growth of HFCS in West Europe to be rapid. This is not the case, however, and the major reason is the policy of deliberate restriction of HFCS growth in the EEC. Because of the overriding role of EEC policy in relation to market forces, it would be useful to begin by briefly outlining this policy for, without an appreciation of it, the data presented in the subsequent tables would lose much of their force.

In 1967, in an effort to restore the competitive position of starch the EEC introduced measures to subsidize its production. Although the intention was to restore the competitive position of starch vis-à-vis petrochemical-based products (e.g., paper), by 1974 this subsidy was extended to glucose producers, who were producing this product from corn as well as from wheat and potato starch. This subsidy was carried over into the 1975 regulation governing the common organization of the Community's cereal market. At about this time, however, the production of HFCS (called isoglucose in Europe) had begun and it benefited from the subsidy. In 1977, the policy was reversed. The subsidy for HFCS was abandoned as HFCS capacity expanded, and several plans were announced by producers for further increases in output. If these developments had gone through, they would have posed a severe threat to EEC beet production, which was at that very time being encouraged in Europe.

In the EEC, beet sugar was subject to a production levy, linked among other things to the EEC-ACP Lome Sugar Protocol. To maintain the competitive position of beet sugar, this levy was applied to HFCS. It was also further announced that HFCS producers would have to help bear the costs of exporting sugar surpluses from the EEC. These policy measures were challenged in the European courts by the HFCS producers, who won a declaration in October 1978 that the levy as it was then applied was invalid.

Following on this decision, the EEC Commission proposed a production quota system similar to the one in use for sugar. Basically, HFCS output was categorized into three parts: namely a basic or A quota calculated on previous production; a B quota equal to 27.5% of the A quota, on which a levy is raised; and a C quota, which has to be exported outside of the EEC, without any financial assistance from the Community. After being challenged, these arrangements were declared invalid by the European courts on procedural grounds. They were amended and subsequently reintroduced by the Community, surprisingly with retroactive effect. This lasted until 1980. In 1981, a new common regulation for sugar and HFCS was introduced for the following 5-year period. Basically, this regulation limits EEC production of HFCS to a ceiling of 200000 t for the period.

The pressures existing within the EEC to limit HFCS production do not only arise from beet producers, whom it is already clear the Community wishes to support in preference to both HFCS producers and imported cane sugar, but the ACP grouping of cane sugar countries also, who are anxious to preserve their market position. Here there is a definite convergence of interests with the EEC's domestic beet sugar producers in the struggle to preserve markets against HFCS competition. Because of this, it would be fair to conclude that market forces will shape the future of the EEC's production of HFCS far less than under usual circumstances.

Examining the EEC's HFCS industry, it is immediately noticeable that the EEC is a net importer of corn. It produces only about 60% of its domestic requirements. The EEC, however, has a large, complex, and highly differentiated industrial market in which the demand for liquid sugar is quite substantial. The data in Table 30 show the EEC sweetener consumption for the sugar year 1980–81. Here, total sweetener consumption amounted to more than 11 × 10^6 t as compared with 12.7 × 10^6 t in the U.S. The consumption of cane and beet sugar was 9.8 × 10^6 t, which is a larger quantity than in the U.S. (8.2 × 10^6 t). This reflects both the support for beet sugar in the Community and its commitments under the Lome Convention. Corn sweetener contribution to total sweeteners used amounted to 11.6%, as compared with the U.S. figure of 35%; Japan, 24%; and Canada, 19%. The Community's HFCS production in 1981 totaled only 176000 t or 14% of all corn sweeteners used or 1.6% of total sweetener consump-

Table 30. EEC: estimated nutritive sweetener consumption (1980–81) (10^3 t, dry matter).

Country	Sugar	Corn syrup	HFCS	Dextrose	Total corn	Total sweetener	Corn %
Belgium	355	32	11	19	62	417	14.9
Denmark	240	14	1	8	23	263	8.7
France	2030	80	26	45	151	2181	6.9
Germany	2150	135	55	70	260	2410	10.8
Ireland	165	28	0	15	43	208	20.7
Italy	1775	65	18	35	118	1893	6.2
Netherlands	660	80	30	43	153	813	18.8
United Kingdom	2380	380	35	55	470	2850	16.5
Total	9755	814	176	290	1280	11035	11.6

Source: Vuilleumier (1981a,b).

tion. This makes HFCS production in Europe the least developed of the major Western industrial regions. As the data in the table indicate, in the European Community, the major producers of HFCS are West Germany, the U.K., France, and the Netherlands, but the totals produced (the highest being 55 000 t in West Germany) are relatively small.

The same data are presented in Table 31 on a per capita basis. Here the highest use of HFCS is in the Netherlands where the figure is only 2.1 kg/year. Sweetener consumption in Europe is very high, ranging from 61.1 kg in Ireland to 33.1 kg in Italy. Four countries, Denmark, the Netherlands, U.K., and Ireland exceed an annual consumption of 50 kg, and apart from Italy, West Germany (39.4 kg/year) is the only country with an annual consumption of under 40 kg/year.

Finally, in Table 32 data are given on the allocation of HFCS quotas for the period 1981–85/86, and the production capacities of various EEC firms. These data show a total production capacity of 288 000 t, as compared with actual output of 195 333 t. The largest capacity resides in Belgium (155 000 t) followed by West Germany (90 000 t), the U.K. (72 000 t), and France (55 000 t). Because

Table 31. EEC: estimated nutritive sweetener consumption per capita 1980–81 (in kilograms, dry matter basis).

Country	Sugar	Corn syrup	HFCS	Dextrose	Total corn	Total sweetener	Corn %
Belgium	36.1	3.3	1.1	1.9	6.3	42.4	14.9
Denmark	46.8	2.7	0.2	1.6	4.5	51.3	8.7
France	37.9	1.5	0.5	0.8	2.8	40.7	6.9
Germany	35.2	2.2	0.9	1.1	4.2	39.4	10.7
Ireland	48.5	8.2	0.0	4.4	12.6	61.1	20.6
Italy	31.1	1.1	0.3	0.6	2.0	33.1	6.0
Netherlands	46.9	5.7	2.1	3.0	10.8	57.7	18.7
United Kingdom	42.7	6.8	0.6	1.0	8.4	51.1	16.4

Source: Vuilleumier (1981a,b).

Table 32. EEC: 1981–85/86 estimated HFCS 42% (isoglucose) quotas, production, and capacities (tonnes dry matter).

Country/location	Basic "A" quota	"B" quota	Total quota	Production	Capacity
Belgium					
Amylum/Aalst	56667	15583	72250	75000	80000
Denmark	—	—	—	—	—
France					
Roquette Freres/Lille	15887	4135	20022	20000	35000
Greece					
Biamyl	6376	1502	7878	6000	13000
ZAAE	4146	976	5122	5000	10000
West Germany					
Maizena/Hamburg	28882	6802	35684	35000	55000
Ireland	—	—	—	—	—
Italy					
FRAGO/Milano	10704	2645	13228	11761	20000
SPAD/Spinola	5865	1257	7243	7572	10000
Netherlands					
DZB	7426	1749	9175	7000	20000
United Kingdom					
Tunnel Ref. Ltd/London	21696	5787	27483	28000	45000
Total	157649	40436	198085	195333	288000

of the distribution of capacity, there is intra-EEC trade in HFCS, but no extraregional exports and hence no C quotas. In this regard, taken as a group, the EEC conforms to the picture of an industry developing on the basis of satisfying its internal markets first.

Given the role of EEC policy in shaping HFCS production, it would be meaningless to make projections based on the usual elasticities, population growth rates, past output, etc. The real issue is what the EEC policy will be, because already for the 5-year period of 1981–86 basic output is fixed at 200 000 t. Although the beet farmers' lobby is clearly dominant at the moment, powerful interests are shaping up against it. Thus, the U.K. group of EEC consumers, in a submission to a Select Committee of the House of Lords on the European Communities (EEC Sugar Policy) made the following submissions (House of Lords 1980:72):

> Isoglucose: CEGG is opposed to the application of the system of quotas and levies to isoglucose. We consider that the product is being taxed and penalized simply because it competes with sugar.

To the same Commission the U.K. Group of Industrial Users of Sugar included the following statement in their memorandum (House of Lords 1980:60):

> The UK industrial sugar-using associations cannot support the Commission's proposals for the 1980–85 sugar regime. Their views may be summarised as follows. . .they are unjust to the isoglucose industry.

The Select Committee in its own conclusions observed (House of Lords 1980:XIX):

> The reason for the Commission's proposal to incorporate isoglucose and sugar in one composite regime is not given. Were the proposal to mean that some flexibility existed for isoglucose and sugar to compete with each other, rather than isoglucose production being strictly limited by its production quotas, then the proposal could be viewed as the development of a Community sweetener policy. Unfortunately this is not the case. If anything, the proposal is slightly more restrictive as the total of isoglucose production quotas has been lowered by 8 000 tonnes (4.5 percent). The proposal appears to be mainly a tidying-up operation by the Commission, whereas the Committee would welcome the evolution of a genuine sweetener policy which gave consumers unrestricted access to all forms of sweeteners.

It is clear from the foregoing that the technological impact of HFCS on Europe and subsequently on the Caribbean through the Lome Convention would depend on what future policies emerge in the Community. This issue will be discussed again in the final chapter of Part I of this study.

Other HFCS Production

A miscellaneous group of countries in Eastern Europe, Western Europe outside the EEC, Asia, Africa, and Latin America produce or have plans to begin shortly the production of relatively small quantities of HFCS. In 1980, output from these sources totaled 132 000 t, and by the end of 1984 was estimated at about 240 000 t and projected to reach 610 000 t by 1985. Data on these producers have been hard to come by, and what follows is a summary of the latest available position. It should be noted that, in all the instances cited, HFCS production is, or will be, geared to the beverage sector of the sweetener market. In general, it would be fair to say that an interpretation of press releases, discussions with persons in the industry, and other similar sources suggest that the most important considerations behind this development are

(a) Where internal protection of sugar results in high sugar prices this acts as an incentive to pursue the development of alternative sources;

(b) National policies aimed at self-sufficiency in industrial syrups; and

(c) The expectation that HFCS technology can be transferred to other starch sources: cassava, yuca, rice, wheat, sorghum, and sweet potato, depending on indigenous availability.

Europe

Yugoslavia has completed one plant with an annual capacity of 40000 t, and another is currently under consideration. Spain has three plants producing HFCS with an annual capacity of 70000 t and an output in 1980 of about 55000 t. The future of the industry is, however, bound up with the eventual outcome of its relations with the EEC. Portugal has plans to open one small plant with an annual capacity of 15000 t during this year. In Eastern Europe, one plant has been recently commissioned in Hungary, with an annual capacity of 50000 t. In the USSR, Romania, and Bulgaria discussions are advanced for the construction of HFCS facilities. Reports indicate a 70000-t plant will soon come into operation in the USSR, whereas the Romanian and Bulgarian projects are being hampered by foreign-exchange scarcity. At the moment, however, these countries are closely observing sugar prices and the probable impact of current negotiations to introduce a new international commodity agreement before embarking on construction of their HFCS facilities.

Latin America

In Latin America, Argentina is the major producer of HFCS at present. Current output is about 80000 t/year. Uruguay has recently announced the planning of a small plant (annual capacity of 15000 t). Significantly, the consortium involved in this project includes the local Coca Cola bottler. Peru has undertaken feasibility studies for a plant with a 50000-t capacity. Mexico has recently commissioned a 100-t/day plant to produce glucose corn syrup, whereas the Brazilian subsidiary of CPC has commissioned a 200-t/day plant, also to produce glucose corn syrup. The construction of wet-milling plants to service these corn-sweetener plants may well be the forerunner of HFCS production. Finally, from commodity intelligence reports, Peru seems to be on the verge of making a decision to start an HFCS venture to produce about 50000 t/year.

Asia

In Asia, Indonesia has one small plant in operation, and apparently there is some government interest in establishing others using cassava as the starch base. Pakistan has also announced an interest in HFCS production and the plan here is to use broken rice as the starch base for a 45000 t/year plant. Taiwan had about a year ago announced an interest in HFCS production of up to 50–100 000 t/year by 1985, but this decision is being reviewed in light of the current sugar market situation. South Korea has HFCS plants in operation and it is said that output currently accounts for 100 000 t or 10% of South Korea's total sweetener market. This market is the world's fourth largest and reflects the fact that South Korea has always had a relatively strong corn sweetener industry. In 1980, about 378 000 t of corn was processed — one-third of this amount (125 000 t) was used as sweeteners in a total market of about 650 000 t for all types of sweeteners. China had announced plans to begin output of HFCS during 1983, and Singapore is pursuing prefeasibility studies.

Africa

In Africa, Egypt now has two plants commissioned and expected to go on stream in 1985. These facilities will have a combined capacity of 100 000 t/year. Apart from Egypt, Morocco is the only other country that has indicated definite intentions as prefeasibility surveys are being conducted.

Australia

Recent plans have been announced for Australia to move to HFCS production using wheat as the basic raw material. Firm details are not yet available, but indications are that this is linked to developments in the cereals market.

Chapter 4

Economics of HFCS Production

Industry Development

Since the technological innovations leading to the commercial production of HFCS, sufficient experience has been gained world wide to highlight certain basic considerations that would seem to determine whether an industry can be successfully developed in a country or not. The following eight points are the most important.

(a) For HFCS to be commercially produced, the prevailing levels of income and the degree of industrial development in a country should be sufficiently high so that the demand for sweeteners is large — particularly for industrial purposes. High incomes per capita and a high ratio of manufacturing output to total output are usually associated with other economic phenomena mentioned in the following. In the U.S. market, about 60% of the sugar consumed is for industrial purposes, whereas in a developing region like the Caribbean, even with its exceptionally high levels of per capita consumption of sugar, the industrial use of sugar is less than 40% of the total.

(b) In considering the industrial demand for sweeteners, it is also important that a high proportion of this should constitute a demand for liquid as opposed to solid sweeteners. Where this exists, one would normally find highly developed processed foods and beverage industries, which in turn depend on the prevailing levels of income, size of market, and the extent of industrialization, as well as on such social factors as the degree of urbanization; cultural patterns in food consumption, e.g., preference for convenience foods; and so on. In the U.S., both economic and social factors favour a highly developed convenience foods industry, and this has no doubt facilitated the rapid growth of HFCS in that country.

(c) The market configuration as outlined in (a) and (b) results in there being a high price elasticity of demand for sugar in general, because industrial users of sweeteners are far more ready than households to substitute one sweetener for another, given favourable price changes. This substitution will of course vary from firm to firm and from one segment of the market to another, with the effective limits of substitution being determined by the technical characteristics of individual sweeteners and the foods in which they are to be used. Thus, as Crott (1982a,b) has observed:

> High prices of sugar have more influence on industrial users; price elasticity is greater for them than for household users (except with very high

prices in the case of low income groups). However, surveys indicate that industrial users are equally concerned with stability of price and purchasing prices not higher than those of their competitors. Thus the quantity demanded by industrial users is more responsive to changes in relative prices than the quantity demanded by household users.

(d) Because HFCS is raw-material intensive in its production process, there should be in addition an abundant source of cheap starch, whether in the form of domestic produce or cheap imports. In the U.S., corn supply is so abundant that after satisfying direct consumption requirements and animal feed needs internally, large quantities are available for export and diversion to HFCS production. The other major HFCS producers (Japan, Canada, EEC) do not have abundant supplies of domestic corn so that their industries, unlike those of the U.S., are more dependent on the availability of cheap imported corn.

(e) Other things being equal, where a country is a net importer of sugar, its incentive to substitute with HFCS is greater. Even though HFCS production is highly capital intensive, the necessary investments required to start up an industry may be deemed by the national authorities to be strategically necessary to reduce dependence on the vagaries of the international sugar trade. As already pointed out, therefore, the U.S. along with Canada, Japan, and the EEC are large importers of sugar. In the case of the EEC countries, however, obligations through the Lome Convention have reduced their capacity to substitute sugar imports with HFCS.

(f) HFCS production is also favoured in circumstances where although domestic sugar is being produced it is done so at a relatively high cost. Where this situation exists, it encourages protection of the domestic market and increases the competitive edge of HFCS. Following on this, it can also be noted that HFCS production is favoured in circumstances where, although there may be no domestic production of sugar, imports of sugar enter the domestic market at a high price. As in the case of Japan, this may happen where government policy seeks to support the price paid to overseas suppliers to its domestic market. There can also be extreme circumstances, such as in the EEC, where domestic sugar might be protected *to the point of the deliberate exclusion of HFCS, thereby reversing the logic of these propositions.*

(g) Because of the capital- and skill-intensive nature of HFCS operations, it is also necessary for capital to be available in sufficient quantity, along with the associated expertise in construction and operation of facilities required to make production feasible. Again, this favours relatively developed economies, with a broad base of industrial skills in food, enzyme, and automated-flow technologies and a sound technological infrastructure.

(h) Finally, as noted earlier, the production of HFCS is highly dependent on associated industries, mainly chemicals, enzymes, transportation, storage, and utilities such as water, energy, etc. The chemicals and enzymes used in HFCS production require modern biotechnological industries, which are to be found mostly in the industrialized economies. The volume of products and by-products entailed in HFCS production is also huge and the conditions of storage and transport have at all times to be closely controlled. Again, this places great emphasis on the availability of such facilities. The industry requires reliable energy and fresh water supplies to fuel it. Thus, countries or locations with efficient public utility systems are also favoured.

Cost Structure

An examination of cost structure of HFCS firms, particularly in the U.S., shows that the major components of cost are (a) the cost of corn (3 bushels, 168 lb, to produce 100 lb of HFCS); (b) by-product credits per bushel of corn: 1.75 lb of corn and oil, 1.5 lb of gluten feed, and 2 lb of gluten meal; (c) labour; (d) utilities (water, energy, etc.); (e) enzymes; (f) freight; and (g) fixed costs (overhead). From this schedule it is apparent that the competitive position of HFCS depends on the cost of corn, the price of corn by-products, the cost of labour, utility supplies, enzymes, and freight and fixed overheads. Immediately one is struck with the fact that unlike the case of cane sugar, where a major by-product (bagasse) can be used to generate its own energy for processing, HFCS is a net and substantial user of energy. This may be so, but its by-products, nevertheless, are of considerable value (corn oil, corn feed, and cornmeal). Depending on prices these can account for more than one-half of the raw material cost of production. In addition, two other considerations figure prominently in HFCS production economics. One is of course the prices of cane and beet sugar, which are the major competing products. HFCS prices in the U.S. have been offered at discounts on sugar prices. The data in Table 33 show that HFCS (42%) prices have been offered at 85% of sugar prices in 1977. This declined to 51% in 1982 and rose to 63% in 1984 yielding an average of 69% during the period 1977–84. In the case of HFCS, 55% variety, its prices were offered at an average discount of 76% of sugar prices for the years 1981–84. It should be recalled that the domestic price of U.S. sugar is high because of the protection of domestic producers.

The second consideration is the price of oil, because corn can be alternatively used to produce ethanol for use as a gasolene extender. This has placed a premium on plants possessing a "swing capability," i.e., the ability to switch from HFCS production to ethanol and back again as the market situation determines it. In a 1981 U.S. Department of Agriculture report (USDA 1981:18) it was pointed out that

> Several corn wet-milling firms are evaluating the ethanol (alcohol) market for blending grain alcohol with gasolene to make gasohol. One wet-milling firm is currently producing fuel grade alcohol at its Decatur, Illinois, facility, and also plans to produce fuel-grade alcohol in 1981, under a joint agreement with a large gasolene company. Other firms may follow suit. A major consideration in producing ethanol from corn is whether a federal loan guarantee can be obtained for all or a substantial portion of the cost of investment.

Table 33. HFCS and sugar prices (cents/lb).[a]

Year	HFCS prices		Sugar prices	Ratio of HFCS/ sugar prices (42%)	Ratio of HFCS/ sugar prices (55%)
	42%	55%			
1977	12.44	—	14.66	84.9	—
1978	12.12	—	17.16	70.7	—
1979	13.15	—	18.49	71.1	—
1980	23.64	—	30.76	76.9	—
1981	21.43	23.89	28.33	75.6	84.3
1982	14.28	20.00	28.08	50.9	71.2
1983	17.70	21.83	29.94	59.1	73.3
1984	19.65	22.80	31.10	63.2	73.3

Source: USDA, Sugar Statistics and L.M.C. Commodity Bulletins (various issues).

[a] The sugar price is bulk, dry beet sugar fob plant. 1 lb = 0.454 kg.

Since then, the trend toward plants with swing capacity has increased. In regard to ethanol production, a very important consideration that should be borne in mind is that if producers can switch from HFCS to ethanol using the same plants, then the seasonal nature of HFCS consumption may lure some producers to switch facilities not only as a result of shifts in the demand curve, but in the off-peak periods as well. Table 34 highlights the seasonality of HFCS production in the U.S.

In Table 35 two estimates are presented of the production cost of HFCS in the U.S. These show operating costs ranging from roughly 13–16 cents/lb of the HFCS 42% variety on a dry-equivalent basis and can be compared with the data on prices paid for HFCS presented in Table 33. The two estimates given in this table have been supported by knowledgeable individuals in the industry. It would be useful, therefore, to examine these data with a view toward highlighting factors of considerable importance to the economics of the industry. To begin with, the data reveal that raw corn cost is easily the most significant cost item in the production of HFCS. Within the industry the rule-of-thumb on which operations are based is that a 50% reduction in the price of corn equates to a 1 cent/lb improvement in the cost of producing HFCS, all other factors being equal.

Second, as already noted, the processing of corn generates by-products. In the U.S., the yield on these have accounted for nearly 60% of the corn prices for the period 1978–84. Data on corn costs for U.S. no. 2 yellow maize and the by-product credits obtained by the industry for the period and the net maize input costs that followed are shown in Table 36. The substantial savings obtained from by-products, therefore, make the market prices of corn oil, corn feed, and cornmeal important considerations in determining the final prices of HFCS. In general, the prices of corn feed and cornmeal are sensitive to the animal feed market where most of it is consumed, whereas the corn oil price is somewhat independent, because it is influenced principally by the edible oil market. In concluding this point, it should be noted that the by-product credits have fluctuated, ranging from less than one-half of the total corn cost to as high as three-quarters of the raw corn cost as the data on the average of annual prices over the period 1978–84 indicate.

A third important factor to note is that labour cost in the industry is relatively small, ranging between 7 and 15% of total cost in the estimates given.

Table 34. Seasonality of HFCS consumption (U.S.).

Month	1979 (percentage of total)	1980 (percentage of total)
January	6.2	6.0
February	5.9	5.7
March	8.1	8.3
April	8.1	8.3
May	9.0	9.0
June	9.5	9.4
July	9.2	9.3
August	11.1	11.4
September	9.6	10.0
October	8.4	9.7
November	7.2	6.1
December	7.6	6.8

Source: Drexel Burnham Lambert Inc. estimates.

Table 35. Estimates of production cost of HFCS in the U.S.

Production cost of HFCS	U.S. (cents/lb)	
(a) Raw corn cost (1980)	9.03	
(b) Return from by-products[a]		
Oil	1.38	
Feed	2.79	
Meal	0.75	
	4.92	
(c) Net raw material cost (a–b)	4.11	
(d) Other costs	Estimate A[b]	Estimate B[c]
Enzyme	0.40	0.40 - 1.20
Operating labour	2.00	0.80 - 1.20
Utilities (energy)	0.70	1.20 - 1.00
	3.10	2.40 - 3.40
(e) Total variable costs	7.31	6.51 - 7.51
(f) Fixed costs (overhead)	2.00	2.00 - 2.00
Freight	1.75	1.75 - 1.75
(g) Total	11.06	10.26 - 11.26
(h) Capital investment costs	2.40 - 4.50	2.40 - 4.50
(i) Total (g + h) (42% HFCS)	13.46 - 15.56	12.66 - 15.76
(j) Total (55% HFCS) + 15%		

Note: 1 lb = 0.454 kg.

Source: Adapted from Brooke (1977), Nordland (1980), and Crott (1982a,b).

[a] Three bushels of corn to produce 100 lb HFCS dry matter.

[b] Brooke (1977).

[c] Nordland (1980).

Table 36. Corn prices and by-product credits (cents/lb).[a]

Year	Corn prices (no. 2 yellow maize)	By-product credits	Net cost of corn inputs
1978	6.87	4.95	1.92
1979	7.85	5.58	2.27
1980	8.95	5.17	3.78
1981	9.44	4.80	4.64
1982	7.64	4.76	2.88
1983	9.66	5.12	4.54
1984 (Jan–Sept)	10.16	4.94	5.22

Source: Landell Mills Commodities Bulletins (various issues).

[a] 1 lb = 0.454 kg.

The industry's current operational norm is that labour costs should account for 10% of the cost of producing HFCS. Enzyme costs are also low, ranging from 3 to 7%. The industry's current operational norm is 5%. Energy costs in the estimates are certainly lower than those currently being obtained in the industry because of the rise in energy prices in the U.S. since these estimates were made.

Finally, it should be noted that the levels of capacity utilization or operating rates in the industry have a significant impact on cost. This reflects the high levels of capital intensity and high fixed charges for capital. In the foregoing estimates, these figures are as high as 35% of costs of operation. Because of this consideration, the industry tries to operate at above 90% of engineered capacity for about 330 days/year.

Cost Patterns

Since HFCS operation capacity was first established in the U.S., important changes have taken place affecting its production costs and, at the risk of some repetition, it is important to observe the pattern behind these changes. To begin with, a decade ago the cost of enzymes accounted for 16% of total production costs, now the current operational norm is only 5%. This substantial fall in enzyme costs reflects the rapid development of the biotechnology industry of the U.S., from which HFCS production has benefited. At the present levels of development of enzyme technology, it has been argued that further significant lowering of these costs would have to await breakthroughs in "enzymatic genetics or the discovery of more heat stable varieties" (Nordland 1980:22). Currently, such techniques are being explored, particularly the technique of transforming low-cost enzymes into much more expensive ones, as well as the genetic engineering of bacteria to produce the required enzyme. Important as these developments are, it should be remembered that even if the cost of enzymes were halved the impact on total production costs would not be very significant.

A second pattern to the changes that have occurred is that as a result of the developments in fractionation technology discussed in Chapter 2, product recovery in the industry has increased by as much as 10–15%. It is also claimed that water usage has fallen by half when compared to the batch-production processes used in the first phase of HFCS production (Nordland 1980:22). Such changes have affected production costs favourably. Indeed, in so far as HFCS production may be seen as the convergence of two industries, i.e., enzyme production and corn wet milling, the industry has clearly benefited, and will continue to benefit, from the developments in the biotechnology of enzyme production. Although the point has already been made, however, that significant cost savings do not presently exist in this sphere, I would like to reiterate one of the observations made in the previous chapter, that is, the long-run impact on costs of the progressive improvements of an incremental sort should not be underestimated, whether it is in enzyme technology and isomerizing conditions or elsewhere.

A third observable pattern, which is in keeping with similar developments in other spheres of U.S. industrial life, is that HFCS plants are being continuously upgraded and a number of labour-saving devices are being introduced. Present day operations are far more automatic and computer controlled than previously, leading to a drastic reduction in labour input requirement, while the level of skills in the present labour force has been substantially increased or altered. Thus, it is claimed that "a high fructose syrup plant which required a work force of 130–150 people in 1972 can be manned by 75–90 employees today if full use is made of automation and computer technology" (Nordland and Liebenow 1981).

Contrary to the patterns that favour cost decreases, investment costs and energy costs have risen substantially. Increases in the former set of costs reflect inflation rates over the past decade and the comparatively high interest rates prevailing in the U.S. The industry rule-of-thumb is that whereas initially when the first-generation HFCS plants were built a new facility would then cost US$1 million of investment for every 1000 bushels (1 bushel = 36.369 L (dry)) of daily grind; by 1975–76 this cost was US$2 million, by 1980 US$3.5 million, and by

1981 it had reached $4.0 million. The U.S. Department of Agriculture (USDA 1981:8) put it as follows:

> . . .a medium-sized wet-milling plant with a daily grind of 75 000 bushels (to come on stream in 1983) would cost around $300 million versus $150 million just 6–7 years ago. Moreover, current financing charges are much higher and stricter environmental and health standards through EPA and OSHA regulations must be met.

The worldwide increase in petroleum prices is too well known to dwell upon here. The effect in the industry has been an estimated increase in energy costs from 4% of total costs in 1972, to about 15–20% today. The industry has responded by seeking to conserve energy used in the production of HFCS. Installation of equipment and devices, such as mechanical compressors, heat exchangers, vapour compression steepwater evaporation systems, high-pressure boilers, and turbine systems for generation of electricity and process steam, has become standard in corn refining plants. Currently, it is estimated that these equipment and devices have resulted in a saving of 30–35% of energy use, as compared with first-generation HFCS plants.

An early study by the Department of Economics at Purdue University produced important data on the costs of operating HFCS plants in the U.S. The cost components of HFCS production are corn, 50%; energy, 20%; labour, 10%; chemicals, 10%; enzymes, 5%; and miscellaneous, 5% (Cubenas et al. 1979). The actual cost estimates produced by this study were 9–13 cents/lb for 42% HFCS dry equivalent with the 55% variety costing an additional 7–15% (Cubenas et al. 1979). The study also showed that the scale of operations is highly significant in determining operating costs. Three different capacities (36 000, 72 000, and 108 000 bushels/day) and six different operating rates were used in the calculations. Table 37 shows a summary of the estimates. From these data, both the scope for scale economies in size and the significant economies to be derived from different operating rates can clearly be seen. As scale increases costs fall and as operating rates rise within any given capacity costs also fall.

The cost analysis undertaken in this study indicates that the cost of processing corn into HFCS is not particularly sensitive to any single factor, except of course corn prices and operating rates. The approximate relationship between production costs and operating rates that the study establishes is that "a one percent increase in the specified operating rate lowers production costs by 0.3 percent" (Cubenas et al. 1979). The approximate relationship between corn prices and cost of production, assuming by-product prices remain constant, is for a "one percent increase in corn price, the cost of production increases 0.6 percent" (Cubenas et al. 1979). As the study concludes there is, therefore, a strong incentive for HFCS producers to run a plant as close to maximum capacity as possible. The revealed cases of underutilized capacities shown in the earlier tables are clearly not welcome by the firms in the industry. Indeed, if capacity is underutilized and these firms do not adhere to implicit price arrangements, then the variations in processing margins can be very wide (Cubenas et al. 1979).

All the studies of the HFCS industry in the U.S., and data obtained from interviews etc., suggest that the cost of producing HFCS is lower than that of domestically produced sucrose, whether it is beet or cane sugar. Thus, a study conducted under the auspices of the U.S. Department of Agriculture shows

Table 37. Cost estimates for producing HFCS (various plant sizes and operating rates) high corn prices (cents) for crop year 1977–78.

	Plant capacity (bu/day)[a]								
	36000			72000			108000		
Operating rate	Low	Average	High	Low	Average	High	Low	Average	High
200	10.253	10.621	11.612	9.042	9.409	10.400	8.886	9.253	10.244
250	9.258	9.625	10.616	8.252	8.620	9.611	8.138	8.505	9.496
300	8.594	8.961	9.952	7.726	8.093	9.084	7.639	8.007	8.997
315	8.436	8.803	9.794	7.601	7.968	8.959	7.520	7.888	8.879
330	8.292	8.660	9.650	7.487	7.854	8.845	7.412	7.780	8.771
345	8.161	8.528	9.519	7.383	7.750	8.741	7.314	7.681	8.672

Source: Cubenas et al. (1979).

[a] 1 bu = 36.369 L (dry).

average sugarcane production costs in the U.S. per acre, excluding land, at US$1029 in the 1981/82 crop year. (The figures ranged from US$505 in Louisiana to US$3162 in Hawaii.) The average per ton cost of producing and processing sugarcane (excluding land costs) was US$28.80. The cost of cultivation of sugarcane was 13.8 cents/lb for the 1981/82 crop year. Sugar beet had US$535/acre for nonland cost of cultivation. Nonland cost of beet sugar cultivated was 11.6 cents/lb. Processing cost for cane sugar per pound was 12.2 cents — giving a total of 26.0 cents/lb. If by-product gains are taken out, the net cost of cane sugar was 24 cents/lb. The processing cost of beet sugar was 17.8 cents/lb. Allowing for by-product credits the net cost was 25.3 cents/lb. These costs are significantly in excess of those estimated for HFCS.[2]

Estimates of European HFCS costs indicate a figure of 17 cents/lb in 1977 (see Grosskopf and Schmidt 1977; Smith 1978; Croft 1982a,b). This cost of production was sufficiently low to permit selling prices of HFCS in Europe to be below sugar prices. For the years 1978 to 1980, HFCS prices in the EEC expressed as a fraction of sugar prices were 88, 77, and 77–86%, which is an average discount of 20% and can be compared with the U.S. discounts presented in Table 34. Current estimates generally make EEC costs of producing HFCS on average 15% lower than that of sugar. It has already been noted, however, that for the immediate future, macroeconomic, political, and social policies of the EEC Commission, rather that the competitive effectiveness of any particular sweetener, will determine the pattern of EEC output of HFCS and sweeteners generally.

The conflict of interests between sugar and beet producers and their demand for protection, the postcolonial arrangements of cane sugar marketing, and the rising industrial consumers' interests in favour of HFCS will be determined more by politics than economics. Nevertheless, the cost advantage of HFCS cannot be ignored, for if this is sustained, over the long run it could well emerge as the single most important factor favouring a rapid future expansion of HFCS output in Europe.

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[2] See USDA (1982). Earlier cane sugar cost of production estimates are given at 10.06–14.01 cents/lb in Zepp (1977). Beet sugar cost of production estimates were given as 8.6–11.5 cents/lb in Jesse (1977). Comparing these to the Purdue University figures given in Table 38, it is obvious that HFCS was competitive at that time also.

Chapter 5

HFCS and the Future: An Assessment

Some Current Views

A good place to begin an assessment of the technological impact of HFCS development would be to look at some recently expressed views by knowledgeable persons both within and outside of the industry. Although the literature here is very sparse, the judgments unanimously stress the fundamental nature of the transformation of the sweetener industry that HFCS development has made inevitable. Consider as examples the following published views:

T.C. Earley, formerly Senior Staff Economist, Council of Economic Advisers, Office of the President of the U.S. (Earley 1980):

> [HFCS] has been one of the main forces affecting the market during the past few years and will continue to be so in the future because most of us have still not fully adjusted our thinking and our analytical techniques in response to the very changed circumstances which HFCS has created.

N.A. Kominus, President, U.S. Cane Sugar Refiners Association (Kominus 1980:47):

> Change is the name of the game. The advent of HFCS has changed everything. Unfortunately, not everyone in the US sugar industry has come to accept this change. And I am troubled to find that many world sugar exporters seem to be somewhat indifferent to the threat of HFCS. Hopefully this conference may open some eyes. . .our members are concerned over the technological progress in the corn sweetener industry. The corn people have almost unlimited resources for research and development.

N. Rivero, Chief Commodity Group, Organization of American States (OAS), Washington, DC, U.S. (Rivero 1980:158):

> With regard to the US sugar market the single most important phenomenon of the 1970's was the establishment of the HFCS as a nutritive sweetener.

D.E. Nordland, Chairman, President and Chief Executive Officer, A.E. Staley Manufacturing Co., U.S. (Nordland 1980:22):

> One can conclude that the future is promising for high-fructose corn

> syrup in the United States. It is not without its problems and limitations, but it continues to evolve in a positive manner.

G. Samuels, Agricultural Research Associates, U.S. (Samuels 1982:2):

> From all indications, in the next decade, corn derived sweeteners will continue to substantially increase their share of the market at the expense of sugar.

S. Vuilleumier, Researcher (Vuilleumier 1980:229):

> Future fructose production and consumption is expected to expand beyond traditional areas. Structural changes are taking place in several countries that may eventually create an environment favourable to HFCS development.

Jose A. Cerro, Market Analyst, GEPLACEA (GEPLACEA 1980:29):

> All the foregoing clearly shows that the most important competitor for sugar on the sweetener market is HFCS. Its present participation in sales is, per se, high, and everything seems to indicate that it will continue to rise.

G. Rodrigo Steed, Farr Man and Co. Inc., U.S. (Steed 1981:6):

> Looking at the investment side of corn sweeteners, there is no question that HFCS is very capital intensive, but the feeling we get is that, one way or another, the necessary funds will be available for further expansion. Some reports indicate in the next three to four years 1.5–2.0 billion dollars will be invested in the Wet Corn Milling Industry, and judging by the industry's performance over the previous years, there is no reason to doubt these estimates. We can thus say that the Wet Corn Milling Industry is here to stay, and is the only area of the US sweetener picture which will continue to show a vigorous expansion.

All the judgments expressed in the foregoing support the view that the HFCS threat to the sweetener market is indeed formidable. As with most technological threats, however, there are two dangers to guard against: an overstatement of the benefits of the new products by adherents newly won over to the innovation, and self-protecting skepticism expressed by established interests in the industry who decry the limitations of the new products. As experience has shown, the most likely eventuality usually falls somewhere between these two extremes. It is my view that the HFCS innovation will conform to this experience. After all, it should be remembered that market estimates of output vary between 5 and 8% of total world output of sweeteners by 1990, although in its leading market, the U.S., this could probably represent as much as 30–40% of its market. Such long-range projections are of course always highly speculative, a point that has been repeatedly stressed in Chapter 3.

The business outlook in the HFCS industry is, like other industries, strongly influenced by the general level of economic activity. In the mid-1970s, because of the dizzying heights of sugar prices (1974–75), abounding optimism prevailed and this prompted rapid expansion of capacity. But as sugar prices subsequently fell and temporary overcapacity emerged, pessimism grew to the point where some even claimed that the threat of HFCS had been overstated (Crott 1982a,b):

> The fears that arose in the mid-70's have gradually disappeared. It has been recognized that the impact on the international sugar cane industry

> would be less than feared. At the present time the only country where HFCS is estimated to make a major in-road is the US. . .however the change in the sweetener market in the US brought by HFCS could have a real importance for its traditional sugar supplies.

When prices revived in 1980–81, optimism returned. Currently, with depressingly low sugar prices, caution has reasserted itself. Nevertheless, the tendency to react to "good or bad news" is quite pronounced. Thus, the move by one U.S. company (Savannah) at the end of 1984 to seek exemption from U.S. import quotas for raw sugar imported to make invert sugar with a new technology, immediately prompted claims that sugar's position had been reestablished. Subsequent events have not borne out this optimistic claim in any way. It can be concluded that although the long-term success of the industry is firmly established now, when making judgment on the long-run impact of a technological innovation it is important to appreciate for what it is worth these cyclical phases in business outlook. Often such swings in outlook, although frequently exaggerated, nevertheless do reflect objective changes in the course of economic activity and should not be overlooked as representing only the subjective whims and fancies of producers. It is important, therefore, that precautions be taken against both treating the prevailing business outlook as the only reality and the temptation to treat their exaggerations when they do manifest themselves as having no objective base in economic events. The objective status of HFCS as a cost-competitive alternative sweetener should always be kept very much to the forefront if its long-run impact on the world's sweetener industry is to be gauged accurately.

Long-Run Considerations

The precise nature of the substitution of one technology for another is not very well known. The common view is that based on the product life cycles in marketing, an S-shaped curve would represent the process of substitution. This means that sales of the new product begin slowly, then there follows a period of rapid substitution, followed by maturity to a plateau from which they eventually decline. The product being replaced has a similar S-shaped curve of decline. Although empirical studies have not always supported this hypothesis, one early paper by Fisher and Pry (1971) postulated that the substitution of one technology for another follows the product substitution S-shaped curve.[3]

A later study by Cooper and Schenkel (1976) elaborated on the pattern of technological substitution.[4] They found inter alia that after the introduction of the new technology, sales did not always decline immediately. In a couple of cases, sales of the old technology continued to expand over the entire period, even as sales of the new technology expand. When sales of the old technology did decline it took about 5–14 years to fall below the sales of the new technology. They also found that where capital requirements were not large, the new technology was generally innovated by new firms outside the industry, whereas generally, firms outside the industry first developed the new technology. The new technology was very frequently expensive and relatively crude at first, leading to skepticism about its eventual usefulness. Later, as skepticism receded, the new technology often created new markets that were not available for the old technology. The process of expanding sales of the new technology was to capture sequentially a series of submarkets. Finally, they found that erratic growth patterns of the new technology could be occasioned by "abnormal" economic and social conditions, e.g., war.

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[3] See Cox (1976) whose empirical studies of ethical drug products and nondurable goods did not always support the S-shaped sales curve. The Fisher/Pry study was broadly supported by Hatten's and Piccoli's (1973) empirical studies.

[4] The empirical study of Cooper and Schenkel (1976) was based on 22 separate firms in the following industries and technologies: steam locomotives vs diesel electric, vacuum tubes vs transistors, fountain pens vs ballpoint pens, boilers for fossil fuel power plants vs nuclear power plants, safety razors vs electric razors, aircraft propellors vs jet engines, and leather vs polyvinyl chloride and poromeric plastics.

How do these generalizations in the literature stand up in this particular case? First, the case of HFCS represents a new technology that is principally being introduced by firms either within the broadly defined sweetener industry or firms linked to the corn wet-milling industry. The precise nature of these connections will be elaborated a little further on as it is an important indicator when assessing the future impact of HFCS technology. Second, the new HFCS technology is highly capital intensive and, consequently, the possibility of new firms entering the industry has so far been confined to its ancillary processes, e.g., production of enzymes. Third, the commodity produced is a basic agricultural product that competes in a market for an agricultural staple that is homogeneous and pure. The production conditions of the range of products consumed in the sweetener market is highly variegated, combining rich and poor countries alike and all the varied production conditions implicit in this. Because of such factors, extraeconomic considerations play an important part in production and consumption decisions. In such circumstances, therefore, the industry is unlikely to follow closely the classic pattern of technological substitution, even though the possibility that some aspects of this pattern may be reflected cannot be ruled out entirely. Already one aspect of this, e.g., the sequential capturing of a series of submarkets, is very evident.

Of prime importance at this stage of the analysis is not only the issue of the threat of technological and product substitution but the responses of the existing enterprises to this threat. Response refers here to the ability of those threatened to both recognize and assess the threatening innovation. For this purpose, the traditional intelligence activities of the sugar producers, which have focused only on other sugar producers (whether they be beet or cane), must shift to include innovations in HFCS, as indeed all other sweeteners including the noncaloric types. As it has been observed elsewhere (Cooper and Schenkel 1976:66):

> It would be a mistake to wait until decline in sales of the old technology triggered the need for appraisal of the threat. By then, much of the lead time would have passed. However, this means that the new technology must be appraised when it is still relatively crude. . .it is not enough to judge that someday a new technology will replace an old one. Rates of penetration must be determined.

In the face of a technological threat, firms' response strategies may be categorized as follows (Cooper and Schenkel 1976:66): (a) do nothing; (b) monitor new developments; (c) step up public relations and legal activity to deter market acceptance and expansion of the new technology; (d) increase flexibility of the existing enterprises/plants to respond to future developments, if necessary; (e) take evasive action by decreasing dependence on the most vulnerable segments of the market; (f) upgrade the existing technology; (g) resort to price cutting, sales promotion techniques, etc., to maintain sales; and (h) participate in the new technology.

In this instance, although the new technology is being developed within the corporate structure of the most industrialized capitalist country, the product that is threatened the most, sugar, is produced in a wide array of agricultural systems of the developed and developing world. Confronting the highly oligopolistic structure of the U.S. high-fructose syrup industry is a multitude of inadequately organized agricultural producers. Indeed, the producers of the two main forms of sugar (beet sugar and cane sugar) stand in direct competition to each other. This means that a coordinated sugar industry response would be particularly difficult to achieve.

Furthermore, the cane sugar-producing industry is several centuries old and in its maturity it has tended to ossify around certain R&D practices. These are confined to improved cultivating practices, improved plant varieties, better pest control, and more efficient conversion processes from the sugarcane plant to sugar, improved reaping and transportation of cane, as well as concern about by-product utilization. Developments that have occurred in sucrochemicals, which will be examined in the next section, have all been pioneered by the TNCs who process this sugar in the industrialized countries. Within the Caribbean region, which is typical of other developing regions, these developments are not being monitored. Indeed, knowledge of HFCS and the threat it constitutes is vague. From all appearances, therefore, the Caribbean cane sugar industry is responding by "doing nothing." Where monitoring of global developments takes place, it is perfunctory and more often than not confined to occasional studies by researchers in such organizations like GEPLACEA, or the Association of Sugar Technologists of the Caribbean. The technological impact and the future growth of HFCS would seem at this stage, therefore, to depend very heavily on the following factors.

First, it will depend on the overall growth of the demand for sweeteners, which is a function of population growth, incomes, etc. As noted earlier, the revealed pattern of demand is a nearly static or low overall global demand (unlikely to exceed in the best estimates 2.5% per year). In the developed countries, per capita sweetener demand is tending to fall or at best remain static. In the developing countries, per capita demand is rising, but from the existing pronouncements and agricultural plans, the drive seems to be for self-sufficiency in sugar production; consequently, the impact of this rising demand on world trade will be largely negated.

Second, it will depend on the technical substitutability of corn sweeteners for sucrose. The tendency is for corn sweeteners in the industrialized countries to increase their range of users and so outstrip the growth of sucrose sweeteners, both liquid and solid. As this substitution of corn sweeteners for sucrose develops, the growth of HFCS will further depend on its technical substitutability with other corn sweeteners, i.e., corn syrups and dextrose.

Third, because the output of HFCS is directly competitive with sucrose, the future course of sugar prices will determine the extent of the market. This factor is distinct from the technical scope of substituting sugar with HFCS. Unfortunately, sugar prices are extremely difficult to forecast. Although in the postwar period a more or less definite, 6-year cycle of sugar prices seemed to have emerged, since the commodity boom of 1974 and the subsequent collapse, stagflation, and emergence of major structural problems confronting the global economy, the future course of all prices is in doubt let alone a highly volatile price like that of sugar. One might, however, conclude that the past and likely future volatility of sugar prices will operate as a dis-incentive to the use of sugar and an incentive to the substitution of the much more price stable HFCS in many countries. This effect will be independent of the effective differential between the price of HFCS and sugar prices.

Fourth, the growth of HFCS will depend on the future course of corn prices. The price of corn (both gross and net) is the principal cost factor in HFCS production. In the U.S., corn is produced in abundance so that direct consumption needs and animal feed are amply met. The by-product prices of corn are also dependent on these factors. To date, HFCS has been marketed at a discount against sugar prices. One advantage of the corn price is that it is more stable than that of sugar. But because corn can be used to produce ethanol, the future course of corn prices will also be dependent on the price of petroleum products. In other territories where corn is imported and an HFCS industry exists, e.g., Japan and the EEC, the course of international grain prices will determine the degree of substitution that takes place.

Fifth, although many technological innovations have occurred since HFCS was first commercially produced, it is still by industrial standards a "young" product. This means that there will almost certainly be further technological improvements. The speed with which these occur and are commercially adopted will determine the future competitive threat of HFCS. The critical technological hurdle that remains is the crystallization of the product. Although this is already technically possible, the process is not yet commercially successful. The small plant producing crystalline HFCS, which is in operation in Savannah, Illinois, sells the price of its products as high as US$1/lb. Crystallization of HFCS still remains the "big prize" to be seized in the sweetener industry. This apart, however, other significant technological improvements can be anticipated, notably in the field of enzyme efficiency and energy-saving and labour-saving automated processes. Although these gains will not be as large, proportionately, as previously, the continuous upgrading of the product that they establish can only enhance its competitive position in the sweetener market.

A sixth consideration is that the commercial application of HFCS technology depends on the availability of capital and the likelihood of processing margins being wide enough to justify investments in the product. Over the past 6 years the world economy has gone through major upheavals, and the process of structural readjustment is still under way and far from completed. In these circumstances, the business outlook is not usually as sanguine as it would be in periods of boom and rapid expansion. As a consequence, investments in a new technology will be approached with greater caution and hesitation. The first introduction of HFCS occurred during a boom period in sugar prices. Since then, evidence of overcapacity in the industry emerged in the late 1970s and the industry no longer supported the buoyant expectations of the earlier period. The partial recovery of sugar prices in 1981 led to some return of optimism. Presently, however, sugar prices are at a low with a glut of world sugar, and the current outlook, therefore, is not particularly encouraging for investments that will mature in the medium term.

A seventh factor that will influence the growth of HFCS is the size of the noncaloric sweetener market. At the moment this is small, less than 1% of world sweetener consumption, although in the U.S. and Canada it is estimated at 16% of their sweetener market. This market is currently dominated by saccharin, but health concerns about this product are driving consumers in the wealthy countries to look for safer noncaloric sweeteners that meet the qualities of taste etc., discussed earlier. If Aspartame can achieve this, then not only HFCS but indeed all caloric sweeteners would be threatened. In addition to Aspartame, efforts are being made to modify sucrose and produce a supersweetener (discussed in Part II), but the search is on for natural supersweeteners like the West African tropical berry (*Thaumatoccus danielli*), which it is claimed is 3000 times sweeter than sucrose.

The eighth and final factor that will be mentioned here is the sweetener policies that are pursued in both the established HFCS countries and those likely to move into production in the near future. As far as the latter group is concerned the main incentives are the availability of domestic starch, an insignificant or insufficient sugar industry, and a significant soft drinks and beverages sector. Already, as has been noted, countries like Pakistan, Australia, Korea, the USSR, Argentina, Indonesia, and China are producing or have advanced plans for the commencement of HFCS production. In all these cases, the soft drinks sector is the main target, and in at least three cases a substitute starch is being used (i.e., broken rice in Pakistan, cassava in Indonesia, and wheat in Australia). Since isoglucose can be produced from other raw materials, e.g., wheat, potatoes, cassava, and rice, the availability of rice, sweet potato, and cassava should make a difference. The Caribbean region, however, is already well endowed to produce cane sugar and it is unlikely that the substitution in favour of HFCS would occur. In other Third World countries, where corn is available or domestic production of cane is not feasible, HFCS may emerge as an important commodity. This development is likely only over the very long run. For the medium term, sweetener policies in the established markets, particularly those of the U.S., Japan, and the EEC will be most crucial for the industry. The major policy directions in these markets have already been indicated. In the EEC over the next 5 years production of HFCS is being deliberately limited to 200 000 t as the Community pursues its policies of support for its domestic beet farmers and its obligations under the Lome Convention. Market forces are, therefore, presently playing a very minimal role in the evolution of HFCS output in the EEC.

In the U.S., the position is somewhat to the contrary. Despite concern for its domestic sugar producers and the import policies being pursued market forces are the key elements in the growth of HFCS in the U.S. Because of this it is important to note that the U.S. firms that produce HFCS have substantial stakes in cane, maize, and beet sugar production, as well as other agricultural based products, e.g., soybean and flour. Despite the stake in other sweeteners the tendency has been to expand HFCS production. Thus, to take a few examples: American Maize (corn) and Amalgamated Sugar (beet) have a joint-venture HFCS project to expand capacity by 100%, Amstar (the largest U.S. cane refiner and second largest beet producer) is to expand capacity by 80%, ADM (soybean, flour, corn) will expand by 50%, CPC (corn) will expand capacity by 180%, Great Western (beet) will expand HFCS capacity by 400%, and Holly Sugar despite declining earnings and a long (21 months) proxy war is also expanding new capacity.

In light of the interests in various sweeteners that these firms have, their willingness to expand HFCS is to my mind the single most significant pointer to the confidence that they have in HFCS as the sweetener of tomorrow. This confidence does not rule out periods of pessimistic outlook, as when sugar prices are very low and overcapacity manifests itself, as it has already done from time to time. But because the long-run commitment is there, such periods of downturn in HFCS activity may lead to price cutting given the large, capital-intensive overheads of these industries. If the gains of the new technology are seriously reversed then a switch to ethanol production becomes possible as this production basically uses the same plant designs as HFCS.

As developments proceed, the HFCS producers who presently sell at a discount on sugar prices are more and more likely to set price ceilings that will progressively eliminate all inefficient cane and beet producers. These latter groups will have to depend more and more on subsidized or protected arrangements, whether they be domestic support policies of the U.S. and the EEC or regional and international price support schemes like the Lome Convention and the ISA.

In conclusion, therefore, HFCS represents the introduction of a sweetener based on very highly advanced sections of modern industry, e.g., biotechnology, automated-flow processes, and waste management. To a mature traditional industry like sugar, developed and still largely practiced on the basis of inefficient agricultural methods and systems, the threat of HFCS is very likely to be all but mortal. It is well to bear in mind the following observation of the Cooper and Schenkel study referred to earlier (Cooper and Schenkel 1976:68):

> . . .that traditional firms. . .continued to make substantial commitments to the old technologies, even when their sales had already begun to decline. . . perhaps this demonstrates the difficulty of changing the pattern of resource allocation in an established organisation.

The threat posed to organizations that are "established" and "traditional" should be combined with an appreciation of the fact that industrial changes are most radical where the newly innovated product serves more or less the same purpose as the existing one but has an entirely different technological base — as is the case with sucrose and HFCS. Furthermore, although HFCS is already a technically advanced product, experience in other industries would suggest that technical improvement will continue and peak after experience in its commercial application is deepened. Already in the short period of time since it has been introduced this can be observed. The threat to sugar, therefore, is one that will progressively get worse unless cheaper and entirely new ways of cultivating and processing cane sugar and beet sugar are found. Unfortunately, no such technological innovations are on the horizon.

Caribbean Position

Whatever the eventual outcome will be of the competition between HFCS and other sweeteners in the markets of the U.S., Canada, EEC, and Japan, one result is beyond doubt — the brunt of this competition will be borne by imports.

It is only to be expected that if internal adjustments of sweetener markets are taking place that domestic public policy would shift as much of the burden as is possible onto foreign producers. One can, therefore anticipate that as HFCS output grows imports will be the first casualty as import restrictions are imposed. If this occurs, Caribbean sugar, which is mainly export sugar, is bound to be affected. Such a development will naturally compound the problems facing the region's industry referred to in Chapter 1.

My interpretation of the response of North America, EEC, and Japan is not intended to make light of the long established obligations of these countries to maintain real levels of support for sugar exports from Third World countries. The U.S. import quota system, the CSA, and later the Lome Convention all testify to the fact that policies of guaranteed market and prices have been introduced by these industrial countries in fulfillment of these obligations and with the intent of fostering the growth and eventual competitiveness and stability of Third World sugar exports. But the CSA, and later the Lome Convention, arrangements have had to struggle to survive against powerful economic and political pressure groups within Europe. At the moment, the real level of support within the Lome Convention is nowhere close to that offered by the old CSA. Similarly, in the U.S. its current global import quota is 2.31×10^6 t (1984-85) down from import levels of twice that in the late 1970s. Although traditional sugar refiners in these countries may favour the policy of encouraging imports of sugar from Third World countries, other domestic sweetener producers and consumers are bound to resist this if it means higher prices or external subsidies or both.

Given these realities, an important case can be made for a Caribbean approach to an international sugar agreement that does not only advocate an agreement for sugar but also advocates an international plan to regulate the development of all sweeteners, caloric and noncaloric, including HFCS, in an effort to ensure an orderly and planned evolution of the world's sweetener industry. Such a plan is not intended to protect inefficiency, but, at the same time, it presumes that what passes for "market allocations of sweetener production capacity" will not necessarily be socially just and equitable. As already noted, the "free market" for sugar is a misnomer as the industry is wedded to special arrangements governing production and sales.

As noted in Chapter 1, although sugar output has been declining regionally, sugar remains an important part of Caribbean economy and society. The region's commitment to an orderly and rational development of the world's sweetener industry should, therefore, be as great as that of any other country or group of countries. Because of this, a definite response that is more than the "do nothing policy," which is presently being practiced, is called for. An important step in this direction would be to make efforts to provide on a regional basis an efficient intelligence and monitoring capability to cope with the threat posed by HFCS to the region's overseas markets. I suggest a regional, as distinct from a national, basis for the obvious reasons associated with economies of scale.

Monitoring is a vital aspect of managing technical innovation. According to Bright (1970) monitoring involves four basic activities: (a) scanning the scientific, industrial, and social environment for key signals that may be indicators of important technological changes to follow; (b) closely identifying the possible consequences of the technological changes perceived; (c) verifying the speed and direction of the technological changes and the effects of their use by the institution on whose behalf the monitoring is undertaken as well as their use by competitors; and (d) presenting the data in a way that can make it possible for management to decide about its organization's reactions (Bright 1970; Utterback and Brown 1972).

Such activities are inevitably complex and the difficulties that they entail should not be underestimated by the proposed regional authorities in the sugar industry. Indeed, it is perhaps such difficulties that have in the past contributed much to the response of "doing nothing." The uncertainties surrounding technical changes have been categorized as those of a "generalized" type that stem from an insufficient knowledge of cause-effect relationships, those of a "contingent" type that stem from the fact that no organization can control all the elements of the environment whose actions can impinge on it, and "internal" uncertainties that exist in all organizations because they are based on limited resources, interdependent groups, and functions and are also affected by decisions made within them (Utterback and Brown 1972:5-6). In response to this situation, Utterback and Brown (1972:6) have suggested a simplified but effective method of monitoring that basically involves two steps:

> 1) identifying 'signals' of change in embryonic stages; 2) gathering information on appropriate phenomena and parameters to determine the rate of advance as well as the character and form that potential impacts of the change might take. This is essentially a method for dealing with contingent uncertainty. Prediction is improved by waiting for at least some of the environmental reactions to become clearer and by following this process until one or a few alternatives are clear.

It is monitoring along these lines that I am recommending. Needless to say such monitoring to be effective should at least be as international in character as the diffusion of the technology. Because of their relatively closer affinity to our environmental conditions, special care should be taken to monitor the development of HFCS production and technology in the Third World and Eastern Europe. This again is a very difficult task because of problems of data collection and dissemination. Indeed, this study, while hopefully adding to the information pool available to the region, is itself most deficient in this area. It should perhaps be cautioned here that the diffusion of HFCS technology is not only a multistep process, but the probability of a given firm (or country) adopting a product or process is an increasing function of the number of firms (countries) in the industry already using it and an increasing function of the profitability of doing so.

The pursuit of an international agreement to regulate the production and marketing of all sweeteners, together with the development of a regional intelligence and monitoring capacity, does not constitute a sufficient response to the threat. Such measures are primarily defensive. What is also needed is the rational pursuit of efforts to determine what are the technological possibilities of using sugar for something more than a sweetener. This task is the subject of the second part of this study. One final word is, however, needed and that is a reiteration of an earlier observation that the interconnection between the threat of HFCS and the development of alternative technologies to transform sugar into products other than sweeteners must constantly be kept at the foreground of our understanding. If this is done then the recommendations that emerge from the first part of the study are not only incomplete but logically cannot be taken further at this stage.

Part II

The Challenge—the Technological Impact of Sucrochemicals

Chapter 6

Industrial Uses of Cane Sugar By-Products

Throughout its history, the cultivation of the sugarcane plant has been primarily oriented to the production of sucrose with varying but nevertheless limited uses of its by-products. In this chapter, a starting point will be provided for an inquiry into the challenge held by sucrochemicals by delineating the broad industrial potential of the sugarcane plant before pinpointing the industrial potential of one of its products — sucrose.

On average, for every 100 t of sugarcane ground the following is produced: (a) 11.2 t of raw sugar (98.5 Pol.); (b) 5.0 t of surplus bagasse (49% moisture) = 1300 kW·h surplus electricity; (c) 2.7 t of molasses (89 Brix; sp. gr. 1.47); (d) 3.0 t of filter mud (80% moisture); (e) 0.3 t of furnace ash; and (f) 30.0 t of cane tops/trash. These quantities are industrial averages and, therefore, vary considerably between countries and between installations in the same country. Thus, in the Caribbean the factories have declined in efficiency to the point where a decade ago the average of 11.2 t of raw sugar per 100 t of sugarcane ground was close to the average for the region as a whole but presently the ratio is as low as 7.8 t of raw sugar per 100 t of sugarcane ground. Or to take another example, where the plant is burnt before it is reaped, there will be cane tops/trash recovery. One set of products excluded from the foregoing list is fly ash and carbon dioxide that escape from the boiler stacks in the factories.

The area of investigation in this study is the industrial uses of raw sugar only in the sense of Paturau's definition: "the conversion of sucrose by chemical mechanisms into products of greater worth" (Paturau 1969:11). The precise mechanisms of this chemical conversion will be discussed in the next chapter, but it should be noted here that it is this area that constitutes the focus of sucrochemistry. The utilization of the by-products (items (b) to (f)) falls into the area known as "extended chemurgy" (Paturau 1969:11). As indicated in the first paragraph, despite the primary focus, it would be useful to look at the broad features of by-product utilization of the sugarcane plant before proceeding.

By-Product Utilization

Bagasse, which comprises cellulose (paper products), pentosans (furfural), and lignin (plastics), is a principal by-product of the sugarcane plant and studies have established that it has a wide range of industrial uses. The most important are

(a) Fuel (electricity, charcoal briquets, and methane and producer gas),

(b) Fibrous products (pulp and paper, paper board, fibre board, and particle board), and

(c) Miscellaneous products (furfural, which is used as a selective solvent in the production of lubricants, furfilic alcohol, and certain pharmaceuticals and pesticides; alpha cellulose used in the manufacture of rayon and acetate fibres, cellophane, plastics, explosives, films, lacquers, and fine papers; plastics; poultry litter and mulch; animal feed; concrete; and soil amendments and mold release for foundry and smelter use).

The use of bagasse to fuel sugarcane factories is universal, making the production of sugar from the sugarcane plant energy self-sufficient. In a number of countries, fibrous products are made from the bagasse along with some of its miscellaneous uses, e.g., poultry litter and mulch. A second by-product is molasses, which is rich in sugar and so can be used as a chemical raw material, a nutrient for microorganisms, or in specific chemical reactions. Its principal uses are listed below:

(a) Direct utilization (fertilizer, animal feed),

(b) Distilling industry (rum, ethyl alcohol, rectified spirits, power alcohol, and alcohol derivatives),

(c) Other fermentation industries (vinegar and acetic acid, acetone-butanol, citric acid, glycerine, and yeast), and

(d) Miscellaneous products (aconitic acid, monosodium glutamate, dextran).

Like bagasse, molasses is an important by-product of the cane sugar industry. Its principal uses are as animal feed and in the fermentation industries. As an animal feed it is heavily traded and competes directly with maize, thereby providing yet another major interconnection between HFCS and sucrose. The use of molasses in the distillation industries is world wide. Recently, however, some countries have been moving to develop gasolene-extender programs, e.g., Tanzania and Mauritius, and they are using molasses as the feedstock for alcohol production, rather than the direct production of alcohol from sucrose.

Filter mud is not a widely utilized by-product. Its major uses are as fertilizers and soil conditioners, animal feeds, wax fats, and building materials extender. The wax and fats in filter mud derive from the water-repellant property of the cane skin. This, however, only represents about 0.18% of the cane weight. From all indications most of the filter mud is either wasted or added to soils and feeds.

The furnace ash derived from the factories can be used as building materials. This, however, constitutes only 0.3% of the sugarcane plant. The cane tops and leaves make up the bulk of the by-products of the sugar plant, accounting for as much as 30% of its weight. Their principal use is in the form of animal fodder, but their availability is contingent on whether or not the canes are burnt before reaping.

In the Caribbean region, by-product utilization is rather limited and the focus of the industry is overwhelmingly in favour of sucrose production. So far, molasses is used to produce spirits, whereas some of it is used also as animal feed domestically or exported. In the distillation of spirits from molasses, there is no significant use of the carbon dioxide and the stillage that are further by-products. The latter consists of unfermented carbohydrates and dead yeast, and usually it goes to waste. Indeed, there have been times when molasses has been so plentiful that it has been buried as a means of disposal. Bagasse is of course widely used in cane-grinding factories as fuel. Some of the surplus also finds its way into poultry litter and plant mulch, whereas a small amount of bagasse board is produced. In the case of filter mud, this is generally spread on the fields as a fertilizer and soil conditioner. The fly ash is sometimes used in this way also. Where the cane tops and leaves are not burnt, small amounts find their way into animal feed.

This relatively limited utilization of by-products in the region is combined with an underdevelopment of local production of refined sugars and syrups. These sugars and syrups are used in the confections, beverages, and food-processing industries, and it is not unusual to find local processors requesting licences for their importation. As a result, it can be concluded that the focus of the region's industry is not only on the production of sucrose, but even more narrowly on the production of sucrose for export and further refining abroad. As noted in Chapter 1, the region's demand is likely to favour a substitution of industrial for household uses of sugar, rather than a rise in per capita consumption. The need for domestic refining capacity is, therefore, likely to increase.

In the study of the HFCS industry in Part 1, it was indicated how important the corn by-product credits were to the industry, accounting for nearly 66% of the gross raw material costs of the industry. Reliable data on by-product credits in cane sugar cultivation in the region are not available, but the evidence suggests that these are small, about 5% of production costs. Beet sugar production also yields by-products, the major one being sugar beet pulp. This is usually available in molasses form (dried and wet) and is almost entirely confined to providing animal feeds.

Bearing in mind this brief background picture of the potential uses of sugarcane by-products, an examination of the industrial potential of sucrose itself follows.

Chapter 7

Potential of Sucrose as a Chemical Feedstock

Properties of Sucrose

In this part of the study, the focus is on sucrose as a potential feedstock for a chemical industry, and not the traditional utilization of by-products of cane sugar production, in an effort to establish a bridge between the cultivation of a traditional export staple and scientific technological innovations on the very frontiers of knowledge. If this is successful then a qualitative shift is envisaged in the pattern of industrialization of tropical agriculture. In the past, this had focused on the further processing of the final product and increasingly better use of the by-products. The outline presented in the previous chapter, therefore, was only intended to provide background information on the scope for traditional by-product utilization. These same by-products, however, would still be available if the sugarcane plant is used to produce sucrose, which is then converted into a chemical feedstock rather than consumed in the way it is at present. Because of this, the previous description would still remain an ancillary aspect of the industry and should, therefore, not be discarded merely because of the shift in emphasis pursued in this study.

Approaching the study of sucrochemistry from a nonchemistry background, I have found that a useful starting point in trying to gauge the potential of sucrose as a chemical feedstock is an appreciation of the major chemical properties of sucrose, particularly as many chemists are not familiar with the field of sucrochemistry. On the basis of literature surveys and discussions with scientists in the field, I believe the following to represent a fair summary of the more important of these properties:

(a) Sucrose is the largest single quantity of a pure defined organic compound available to man. It has a low molecular weight (342) and great chemical versatility. It is so pure that it is claimed that ordinary table sugar contains 99.96% of the molecule sucrose with more than one-half of the remainder being water. Even the raw sugar shipped from the Caribbean has a purity ratio as high as 97.5%. Its bulk derives from the fact that world output of sucrose is currently about 100×10^6 t annually. These two properties, bulk and purity, are important assets of sucrose when considered from the point of view of its possible use as a chemical feedstock.

(b) Sugar is chemically versatile. As Vlitos points out, because it constitutes a "cheap polyhydric alcohol [it] can be used in a wide range of reactions to make resins, plasticizers, surfactants" (Vlitos 1979b:14). Indeed, sugar is so versatile that it is claimed that it is technically possible to produce from sucrose all the chemicals currently produced from petroleum feedstocks.

(c) Sucrose is water soluble, and in some chemical reactions this is an important asset, whereas in others it can be a disadvantage.

(d) Sucrose is readily metabolized by microorganisms, plants, animals, etc. This property makes it biodegradable and is an important advantage over some petroleum-derived chemicals, e.g., detergents.

(e) Sucrose is nontoxic. Not unexpectedly this property widens its range of useful applications, particularly in such areas as food, pharmaceuticals, and cosmetic preparations.

(f) Sucrose readily forms complexes with some metal ions.

(g) Sucrose is hygroscopic, i.e., it has a tendency to absorb moisture.

(h) Sucrose is an important raw material for microbial conversion processes and, because of this, it has been traditionally used in the production of alcohols, organic acids, and so on.

(i) Sucrose is unstable to heat and this has tended to pose problems in certain chemical processes.

(j) Sucrose does not only produce energy but it also has bulk, which gives it an important edge in the search for alternative energy systems, because some of the alternatives being investigated, e.g., wind, nuclear power, and water systems, although producing energy, do not possess bulk that they can pass on to other products.

(k) There are two manifest chemical reactions of sucrose that must be continuously appreciated. One is hydrolysis, which is the inversion of the angle of polarization in the presence of Lewis acids. With water, inversion yields two simple sugars, D-glucose and D-fructose. For the purposes of this study, the point of significance is that for most sucrochemical processes, inversion is undesirable. This, therefore, poses the requirement that reactions must be carried out in the absence of Lewis acids. The other manifest reaction is pyrolysis, which is a more complex reaction than hydrolysis. It is a part of the familiar process of caramelization, which occurs when sugar is heated much above 140° C in the presence of salt or acid catalysts. The products yielded are water and an exceedingly complex mixture of degradative products. As would be expected, pyrolysis would generally be an unwanted reaction in sucrochemical processes, and, therefore, such reactions would have to be insulated from direct contact with Lewis acids and also operate at moderate reaction temperatures.

(l) Sugar molecules (sucrose, hexoses, etc.) are somewhat unstable. As Paturau (1969:11) observes: "These molecules play a most important part in the plant kingdom where they are constantly being formed, broken up and transformed." But what is an asset in biological reactions can constitute serious obstacles in chemical reactions.

(m) Sucrose hydroxyls are usually less reactive than water. This property poses a problem when making derivatives of sugar in aqueous media.

(n) Finally, in sucrose, the high ratio of oxygen to carbon puts a limit on the number of organic solvents that can be used. Petroleum is generally low in oxygen or has exclusively carbon and hydrogen atoms. As a chemical feedstock this makes for good yields. Again, according to Paturau (1969:12): "Thus the theoretical yield/weight from petroleum derived ethylene is 165%, whilst ethanol production by fermentation results in discarding two-thirds of the oxygen and one-third of the carbon, the maximum theoretical yield being 54 per cent."

Such limitations do not constitute insuperable obstacles. As will be observed later, there are ways around them; one being to focus on derivatives that, although having poor to moderate yields may not be easily substituted by other products. Another would be to focus on reactions where a biological process is used, e.g., citric acid, and yet another would be to focus on those reactions where weight loss is minimal but where alternative routings are not easily pursued, e.g., sorbitol, mannitol.

Chemical Operations with Sucrose

The serial presentation in the previous section on the important chemical properties of sucrose was in preparation for the next step of the analysis, which is to determine the nature of the chemical processes on which a sucrochemicals industry might be built. This very important task will be attempted in this section, but reference will be made from time to time to the significance of the properties listed earlier.

The fundamental issue is that to be able to utilize sucrose commercially it must be transformed to other products of greater worth either chemically or microbiologically. Unfortunately, the phrase "of greater worth" is sometimes overlooked in the excitment over important technical discoveries whose importance as a contributor to net worth cannot be presently justified. Leaving this issue aside for the moment, however, there are two major routes in the chemical transformation of sucrose, i.e., chemical degradation and directed synthesis with other chemicals. There are, therefore, three routes: microbial conversion, chemical degradation, and chemical synthesis. Each of these will be examined in turn.

Microbial Conversion

In the case of microbial conversion there are basically two points that should be observed. First, this approach is traditional and perhaps is best exemplified in the familiar fermentation processes. In this conversion, certain vital factors should be noted.

(a) The use of microorganisms in the conversion of one chemical product to another is relatively nonspecific. This means that after suitable treatment not only sugar but most carbohydrate sources can be made into a feedstock. To use this process would, therefore, mean that a chemical industry based on sucrose must be highly competitive, in terms of the cost of raw material, with other carbohydrate sources, e.g., corn, rice, wheat, potato, cassava. In other words, the specific advantage of sucrose could well be lost in the nonspecific microbial conversion process.

(b) Because microorganisms are used in the conversion process, yields are inevitably low, as the microorganism must metabolize a proportion of the sucrose as a source of its energy.

(c) The microbial conversion process has low reaction rates and requires large volumes of the product and long residence times. Although research is improving on these variables, as noted in the case of isomerization of corn to fructose where the use of immobilized enzymes has replaced the older batch-production process, the cost of doing so relative to other processes, e.g., petrochemicals, is a factor that has to be taken into account.

(d) The separation of the wanted product from others in the microbial process poses major technological problems whose solution inevitably raises costs. Thus, for example, the presence of water would normally require an energy input to concentrate and separate the product.

Although the foregoing observations show how restrictive the microbial process is, some of these restrictions can constitute advantages in certain circumstances. For example, the presence of water and associated nonsugars in chemical operations may be desirable. Or the microbial processes can be seen as permitting complex multistep and stereo-specific reactions, and with improved conversion efficiencies this can be an important advantage. Similarly, this process can often utilize substrates of quite low purity and, therefore, can be an important element in the exploitation of what would normally be treated as waste residues.

The second point to observe is the range of products that can be produced by microbial conversion. A wide range of products can be produced as a result of the metabolism and growth of microorganisms in a carbon and energy source such as sugar. The technical task is to find the particular microorganism that can carry out the specific chemical transformations of the sucrose molecules that are required. Although some of these are beyond the current capabilities of organic chemistry, the following are the major products that can be produced:

(a) A wide range of antibiotics, used of course in the health sector.

(b) Gluconic acid. The yield here is 70% of the sucrose used. This acid finds applications in pharmaceutical preparations, where salts are used as a means of introducing trace elements to the diet, e.g., ferrous gluconate (iron) and calcium gluconate (calcium); food and feeds, where it can be used as a source of calcium for chickens, as a stabilizer in shortening, or to prevent excessive browning in deep-fat frying; cleaning compounds, where it is useful for cleaning bottles and metals because as a cleansing agent the acid has low toxicity and corrosive powers; paints, where it is used for its anticorrosive properties in marine applications or it is used as an additive to water-based paints to prevent "flashing" because of the presence of calcium and magnesium.

(c) Xanthan gums. The yield here is 65% of the sugar used. Xanthan gum is a pseudoplastic material with unique rheological properties combined with resistance to temperature and pH changes. It is used in foods to improve oral texture, freeze-thaw stability in frozen foods, and to act as a suspending and thickening agent in relishes and salads and to provide the characteristics of gluten in nonwheat flours; in cosmetics as a suspending and emulsifying agent in toothpastes, ointments, creams, etc.; and in oil-well drilling as a fluid additive because of its compatibility with salts and its resistance to temperature degradation. For oil-well applications it is useful as it has a high fluid carrying capacity and low water loss properties. It is used in many industrial products also as a suspending, emulsifying, and stabilizing agent, especially for some difficult-to-stabilize polishes, cleaners, ceramic glazes, and print pastes.

(d) Biopolymers. The synthesizing of high molecular weight polymers from sucrose is quite a well-known process. It is claimed that this process is an integral part of the metabolism of all microorganisms and is not a surprising occurrence in view of the important role of lipopolysaccharides in the structure of most microorganisms. The best known of the biopolymers is dextran. The yield of dextran is 33% of the sugar used. It finds useful applications in medicine as a blood plasma volume extender; in food processing, as a thickening agent; and in oil-well drilling. There are several plants producing dextran around the world and one is located in the Caribbean (Cuba).

(e) D-Araboascorbic acid (iso vitamin C). The yield here is very low, 15% of sugar used. It is normally produced using a preparation of dried cells of *Penicillium notatum* in sucrose.

(f) Kojic acid along with derivatives for use as pesticides. The organism used is *Aspergillus flavus.*

(g) Fructose, which can be produced from sucrose by the organism *Aspergillus niger.*

(h) Ethanol. This can be produced directly from sugarcane juice or from molasses. Ethanol can be used as a fuel extender, to make potable alcoholic beverages, as an intermediate chemical, and as a chemical feedstock. It is the most important product of this route and as will be discussed in Chapter 9 it is seen by some as the major future product of the sugarcane plant.

Chemical Degradation

The second process is that of chemical degradation. The diagram shown in Fig. 3 summarizes the process. As will be discussed more fully in the next chapter, this route has typified the research work of the International Sugar Foundation (ISF). Experience has shown that it has been, from a commercial standpoint, a generally fruitless endeavour, although as will be shown many technical results have been achieved. The major problem with this route appears to be that degradation products of sucrose are of a lower molecular weight, thereby permitting their synthesization either from cheaper sources of carbon, e.g., petroleum, or even from carbohydrate wastes. There is the additional factor that chemical degradative reactions proceed in a relatively "uncontrolled" fashion, thereby yielding a mixture of products from which the required product has to be then isolated. It would appear, therefore, that on purely a priori grounds the effectiveness of this route has to be restricted to special circumstances where no competitive products can be easily produced. This position is supported by Khan and Forage (1979/80:178): "Despite extensive research in the past in degradation reactions of carbohydrates to yield a variety of products this approach, at present, is non-competitive."

With these cautions in mind, the description can be completed by observing

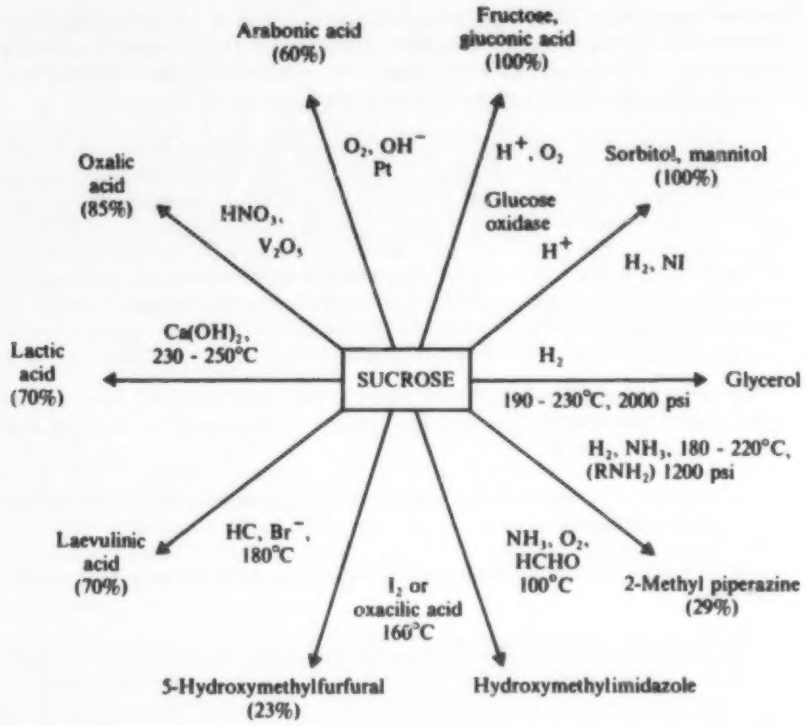
Arabonic acid (60%)
Fructose, gluconic acid (100%)
O₂, OH⁻ Pt
H⁺, O₂ Glucose oxidase
Oxalic acid (85%)
HNO₃, V₂O₅
Sorbitol, mannitol (100%)
H⁺
H₂, NI
Lactic acid (70%)
Ca(OH)₂, 230 - 250°C
SUCROSE
H₂
Glycerol
190 - 230°C, 2000 psi
H₂, NH₃, 180 - 220°C, (RNH₂) 1200 psi
Laevulinic acid (70%)
HC, Br⁻, 180°C
NH₃, O₂, HCHO 100°C
2-Methyl piperazine (29%)
I₂ or oxacilic acid 160°C
5-Hydroxymethylfurfural (23%)
Hydroxymethylimidazole

Fig. 3. Degradation reactions of sucrose.

the various degradation reactions that have been identified and are summarized in Fig. 3. These reactions are as follows:

(a) *Mild conditions of catalytic hydrogenation of invert sugar.* This yields the hexitols, mannitol and sorbitol. These are special products and their output via this route is already commercialized. The sucrose demand, however, is limited as very little sucrose is used in their production.

(b) *Vigorous conditions of catalytic hydrogenation of sucrose.* This yields glycerol with by-products being propanediol, ethyleneglycol, and erythriol. It is estimated that in the mid-1960s about one-tenth of U.S. production of glycerol was produced in this way. Competition, however, from synthetic glycerols led to the closing down of the major plants in 1969.

(c) *Hydrogenation in the presence of ammonia or primary amines.* This yields 2-methylpiperazine or the *N*-alkyl derivatives. The yield has never increased beyond 30% and the result is thought to be uneconomical.

(d) *Direct reaction of sucrose with ammonia.* This yields a complex mixture of nitrogen heterocycles in which dimethylimidazoles predominate. Yields are also unpromising, and this route is thought of as being uneconomical as well.

(e) *Weak acid catalysts at elevated temperatures.* This yields 5-hydroxymethylfurfural. Yields are low, below 25%, and demand for this product is limited.

(f) *Strong acid catalysts at elevated temperatures* This yields laevulinic and formic acids. This route has not been exploited commercially because these products can be obtained from furfural.

(g) *Alkaline degradation of sucrose in the presence of lime.* This produces lactic acid in good yield (70%). The lactic fermentation process is, however, better (yields 85%) and so is the preferred route. Synthetic lactic acid is also being produced.

(h) *Nitric oxidation of sucrose.* This produces oxalic acid in good yields but is still uneconomic when compared with the use of cheaper cellulose and carbohydrate wastes.

(i) *Aerial oxidation of sucrose in the presence of platinum catalysts.* This yields arabonic acid in good quantities and research chemists are sanguine about this possibility.

(j) *Aerial oxidation of sucrose in the presence of immobilized glucose oxidase.* This produces gluconic acid and fructose and the yields here are also thought of as promising.

Directed Synthesis

Given the limited scope for economical application of sucrose through both the processes of microbial conversion or chemical degradation, any promise of a thriving sucrochemical industry has to be based on technological breakthroughs along the third route, namely directed synthesis. The two routes already considered basically seek to use sucrose as a source of simpler products. The approach of directed synthesis regards sucrose as a primary raw material itself and seeks to exploit the opportunities of synthesizing it with other chemicals to produce higher-valued products. This approach makes use of sucrose in the form it is normally marketed, i.e., its pure anhydrous state (Hickson 1977; Vlitos 1977; Parker 1979a,b; Parker and Righelato 1980; Vlitos and Parker 1981). The potential for using sucrose in this way is bound up with the chemical properties of sucrose identified earlier for the object of directed synthesis is to produce reactions with selected synthesizing compounds, and these reactions will be determined ultimately by the reactivity and stability of the sugar molecules.

Because sucrose is essentially a polyhydric alcohol, chemists point out that it has the potential to give rise to an almost unlimited range of derivatives (Vlitos and Parker 1981:40). It will undergo all the typical reactions of alcohol. Following Vlitos, these potential derivatives can be presented by function as shown in the following list (Vlitos 1977). The potential industrial use of the derivatives, based on current knowledge, is noted within parentheses.

The first function is esterification of sucrose using conventional methods leading to polyester. The resulting products would depend on the conditions and the acylating agent that is employed. The second function is etherification and this is also available by conventional routes, although not without some difficulty. The third function is the production of urethanes. The fourth function is the production of xanthates, and the final function is the production of acetals.

Esters — monostearate (surfactant emulsifier), monoacetate (humectant), distearate (emulsifier), hexalinoleate (surface coatings), octaacetate (denaturant plasticizer), octabenzoate (plasticizer), diisobutyrate, hexaacetate (viscosity modifier), monomethacrylate (resin monomer), and polycarbonate (resin intermediate).

Ethers — monooctadecyl ether (surfactant), heptaallyl (drying oil), octacyanoethyl (dielectric), octahydroxypropyl (cross-linking agent in polyurethane resins), and tetracarboxyethyl (chelating agent).

Urethanes — *N*-alkylsulphonyl (surfactants).

Xanthates — *S*-alkylmonoxanthates (surfactant chelating agent).

Acetals — cetyloxyethyl sucrose (surfactant).

A major obstacle in the development of synthetic sucrose derivatives is the "restricted solubility of the reactants in solvents other than those which are similar in reactivity to sucrose itself" (Parker 1979a,b). As will be shown in the next chapter, some of the solvents used, e.g., pyridine, dimethylformamide, dimethylsulphoxide, are very costly if considered on a commercial scale. This has encouraged the search for products that would require no solvents or products that can sell at a price to recoup the cost of such expensive solvents. These issues will be taken up in later chapters, for here the objective is limited to the presentation of the major technical issues at stake in the production of sucrochemicals.

Conclusion

The first two sections of this chapter sought to highlight the technical problems involved in the production of sucrochemicals. Although the focus was on the "chemistry" of the problem, it was impossible to avoid indicating some of the commercial implications in the process. The presentation on the chemistry issues began with a summary of the chemical properties of sucrose to identify its potential as a chemical feedstock and a discussion was given of the technical routes toward the production of sucrochemicals. Three routes were identified and each was discussed in turn. Directed synthesis was identified as the preferred route and a presentation of sucrose derivatives by chemical function was displayed in the foregoing scheme. By way of concluding this chapter, an alternative presentation that groups the products (noted within parentheses) that sucrose can produce by the type of reaction that produces them is offered. This is based on an earlier work of Paturau, and is offered primarily for the sake of completeness of the presentation of this chapter (Paturau 1969). Although it adds no new information, nevertheless it alters the perspective from which the potential of sucrochemicals is presented. In this way it might deepen our understanding of the issues at stake.

Fermentation (Ethanol, butanol, acetone, acetic acid, and citric and lactic acid.)

Esterification (Sucrose octaacetate used in adhesives, as a denaturant, plasticizer, and in cellulosics; fatty acid esters; and sucrose octanitrate (explosives).)

Allylation (Allyl sucrose used as coating materials, adhesives, fast drying paints, varnishes, etc.)

Reaction with propylene (Hypose SP80, which is the trade name for octakis(2-hydroxypropyl)sucrose, used in polyurethane foams as a plasticizer, in resins and glue starches, etc.)

Reaction with phenol and formaldehyde (Explosives.)

Oxidation (Food and pharmaceutical products, e.g., D-arabonic acid used in the manufacture of vitamin B_2.)

Hydrogenation (Sorbitol and mannitol, which is used as a humectant in medicine (e.g., laxatives and blood pressure depressant); propylene glycol, which is used as a polyester resin; and glycerol used in resins and gums.)

Acid degradation (Furfurals used as plasticizers and food and pharmaceutical additives, etc.)

Alkali degradation (Lactic acid, which has a wide variety of uses; methyl acrylate, which is used as an adhesive; polymer; protective coatings; etc.)

Hydrolysis (Fructose used in food and pharmaceutical preparations.)

Chapter 8

Historical Functional Analysis of the Development of Sucrochemicals

With the chemical features of sucrose and the technical routes toward the production of sucrose chemicals having been discussed, a brief examination can now be made of the historical course of research in this field. Only the most general of outlines will be attempted here, but, hopefully, this should be adequate for deepening our understanding not only of the course technical innovation has followed but of the technological hurdles that still have to be overcome. Hopefully, this also will bring greater coherence to the analysis presented thus far.

If careful consideration is given to the evolution of the chemical industry, it can be observed that agricultural raw materials have always been an important feedstock for this industry. Sugar, starch, potash, cellulose, and vegetable oils are among the better known and most widely used of biomass materials. Following on the great oil boom in the middle of this century, however, petrochemical feedstocks became the major input into the chemical industry. Thereafter, the chemistry of agricultural raw material utilization in industry was replaced by the focus on increasingly more efficient utilization of petroleum fractions and their derivatives. This substitution in favour of petroleum, affected not only biomass but was also to the disadvantage of coal, until then also a major industrial input into the chemical industry.

From the industrial point of view chemistry cannot be looked at in isolation from energy. Energy is needed to power industry, to energize transport and communication systems, to heat living places, as well as for producing the fertilizers, pesticides, herbicides, etc. without which a modern agricultural system capable of feeding large urban populations would be impossible. Energy is also needed to produce the minerals that we need, as well as the clothing, housing, recreation, and entertainment facilities without which we cannot live full lives. All this is familiar, but it takes on added significance in the face of the current fuel crisis. This is the second major such crisis to be identified in the period of capitalist industrialization. The first is usually located in the early years of industrialization in the middle of the 19th century in the United Kingdom (and much later in the U.S.) when fuel wood, which was then extensively used, became scarcer and scarcer.

In all the major energy systems used so far, coal, biomass, and petroleum, the raw material generates energy, while the mass it is made up of can be chemically transformed. Some of the newer energy systems being contemplated, e.g., nuclear power, although producing energy, do not possess a mass available for such transformation. In so far as mass, or as it is sometimes put a "harvest of tons," is required by industry, biomass has the advantage of being a truly regenerable resource that can meet the large variety of human energy needs as indicated earlier. This constitutes what I believe to be the long-run, inherent structural advantage of biomass, and, so long as it remains this way, the search for breakthroughs in the efficient utilization of biomass will proceed. It is true that in the past the search for breakthroughs was intensified during periods of critical shortages of fuel (necessity is the mother of invention!) and has receded in times of apparent bountifulness, but the underlying drive in this direction has nevertheless continued and will continue. It is within this category of general considerations, therefore, that the industrialization of sucrose has to be evaluated.

The development of sucrochemistry as a defined field of study is associated with the establishment of the Sugar Research Foundation (SRF) in 1943. The establishment of this institution came at a time not when fuel was scarce but when sugar was thought of as plentiful, and there were fears of disposal of surpluses. The Foundation was established with the aim of pursuing on its own initiative and supporting elsewhere studies on the nonfood utilization of sugar. Despite this mandate, however, during the first 8 years of its life the Foundation concentrated on improving sugar consumption through the systematic dispelling of what it termed as "myths and misconceptions" of the health and dietary consequences of increased sugar consumption (see Hickson 1979:156–157). This purely defensive attitude changed somewhat with the appointment of Professor H.B. Hass, who as Hickson describes it "has gained an enviable reputation by taming the halogenation and nitration of carbohydrates in the vapour phase" (Hickson 1979:157). It was under his leadership that a program of sucrochemistry research was officially launched. This program was defined by Hickson as "the conversion of sucrose by chemical processes, into materials of commercial value" (Hickson 1979:157). It was this definition, he claims, that Professor Hass christened as sucrochemistry. Interestingly, the definition given is not only technical but is commercial in its orientation as well.

The issue of satisfactory solvents for use in sucrose derivatives was raised in the previous chapter. It was not until the 1950s that a major set of new solvents became available to chemists, principally, *N*-dimethylformamide (DMF) and dimethylsulphoxide (DMSO), which could be used in the production of esters and ethers. In the decade 1950–60, after some promising discoveries, chemists in the field became optimistic and began to proclaim that "the non-food uses of sugar would be the panacea for surplus production" (Paturau 1969:11). Hickson describes it graphically: "the Foundation of the mid-1950s developed a high expectation for the potentials of the sucro-chemical programme. An eager technical press greeted new finding, lauding the programme as a breakthrough in the utilisation of biomass resources. . .this fanned the hopes of the sugar producers supporting the Sugar Research Foundation. It certainly was great while it lasted" (Hickson 1979:172). The promising technical results however, could not be translated into commercial successes and as Paturau (1969:11) remarked: "it was soon found that the industrial production and marketing were indeed more difficult than had been expected, especially when in competition with the powerful petrochemical industries and other vested interests." This should not have been surprising as it is estimated that there are 3000 known surfactants alone so that market penetration would always be a formidable task.

The work of Professor Hass and his colleagues did, however, provide some important discoveries with commercial potential. One good example of this was the production of a surfactant ester under a process that was licenced by Dai Nippon Sugar Manufacturing Co. of Tokyo in 1960, and continued by Ryoto Co. in a joint venture with Mitsubishi, to produce the Ryoto esters used in food, pharmaceuticals, and cosmetic industries. The original reaction solvent that was used was DMF, but, because of problems of potential toxicity etc., the company had to invent a process that did not require its use. A second good example of the work of this period is the process for producing sucroglycerides, which are a mixture of sucrose esters and fatty glycerides. This was first used in production under licence by Melle-Bezons of Paris and later the licence was acquired by Rhone-Poulence. The trade name is Celynols. This process is capable of reducing the residues of DMF, which is used as the reaction solvent, sufficiently to permit applications in the food industry. The main market, however, is animal feeds where it is used to reconstitute vegetable oils into skimmed milk for feeding calves. This latter process has been substantially modified and developed by Tate and Lyle Ltd and will form the subject of some extended discussion later.

It is claimed that the very first commercialized sucrochemical to be produced was octaacetate. The development of this product was due largely to work done in the Mellon Institute in the U.S. This product has found two principal uses to date. One is as a plasticizer in the cellulose esters where it is used as a bonding agent in laminated safety glass, and the other is as a denaturant, e.g., in pharmaceutical ethanol. This product has an exceedingly bitter taste, and it is this property that favours its use as a denaturant. The combined markets for these products, however, is small, totaling 50 t/year.

The work of the SRF was often done in collaboration with or at the prompting of other institutions. Thus, the work on the sucrose monoesters of fatty acids was done at the request of the State Government of Nebraska, which was then looking for markets for inedible animal fats, principally tallow. Research into sucrochemicals was also not confined to the SRF even during this heyday. The early work of the Mellon Institute has already been referred to. The Kansas State University has also done important work in the area of testing sucrose esters and other surfactants in the baking industry where several important roles have been identified. In addition, Tate and Lyle Ltd, with its associated research laboratory at Reading University, has been the organization most consistently committed to a comprehensive program of technical work in the area of sucrose chemicals during the last decade or so. Tate and Lyle Ltd will be discussed more fully in Chapter 10.

Although the work of the SRF dominated sucrochemistry research up until a decade or so ago when this role was assumed by Tate and Lyle Ltd, the object of the Foundation's research was to generate information on the chemistry of sucrose, evolving syntheses of sucrose, and determining the properties of the new sucrochemicals created. The emphasis was more scientific than technological (Kollonitsch 1970). It certainly was not commercial as Hass' definition suggests. One result of this has been a virtual neglect of the class of materials known as urethanes. Urethane technology in the West has developed in the industrial milieu of chemical TNCs, and the Foundation expected this to continue. In any case, it felt that it did not have the resources required to make a significant contribution in this area.

A central criticism of the Foundation's research is that it proceeded with far too heavy an emphasis on the degradative products of sucrose. The long list of degradative reactions, which were identified in the previous chapter, is largely the product of chemical research in one way or another associated with the SRF. The criticisms of this approach that were made, therefore, hold true for the Foundation's work. It was not until after much effort in this direction that the Foundation came to accept that this was a dead-end route in commercial terms. It was the route of directed synthesis that would offer the best prospects, but by the time this was realized Tate and Lyle Ltd had assumed a commanding role in the field. The story of the historical development of technical innovation in sucrochemicals will, therefore, have to await the discussion in Chapter 10 for completion.

A second major criticism of the Foundation's work is the energy "wasted" in trying to disprove the health charges laid against sugar in an effort to "stimulate" its consumption. This effort was revived again in 1959–60 and lasted until 1969 as the Foundation concentrated on trying to prove the health dangers of cyclamate, the nonnutritive sweetener that seemed to threaten the sugar market. Referring to this period, Hickson (1979:173) points out that after the introduction of cyclamates:

> . . .the sugar industry became justifiably dismayed and drafted the Foundation to become the point of its defensive stand. Essentially all other kinds of research were abandoned to concentrate a maximum of effort on protection from this extreme economic pressure.

This extreme reaction hindered the Foundation's role in the emerging technology and helped to confirm the dominance of Tate and Lyle Ltd in this field. The analysis of this development will be discussed in Chapter 10.

In summary, therefore, the following observations can be made:

- Research into the nonfood uses of sugar was prompted by the surplus of sucrose combined with the need to find a regenerable resource that could provide an important input into the chemical industry.
- The response of the industry was to establish the SRF in 1943 whose initial interpretation of its task was to disprove the allegations made about the dangers of sugar in the human diet.
- Although the defensive outlook still continued, by 1952, under the guidance of Professor Hass, sucrochemistry as a new field of technical work began.
- The work of the Foundation in this area was helped by discoveries of new solvents, although these were too expensive for commercial use.
- Unfortunately, most of the research was focused on the area of the degradative products of sugar, which from a commercial standpoint, are basically uncompetitive.
- The later development of the approach of directed synthesis was to be associated with the shift in the centre of research from the Foundation to Tate and Lyle Ltd and its associated laboratories at Reading University.

- Although the Foundation shifted the emphasis of its research as indicated in the third and fourth points noted earlier, the development of nonnutritive sweeteners, particularly cyclamate, led to a recrudescence of defensive research work aimed at proving the health dangers of cyclamates. This occupied the Foundation from the early 1960s to 1969 and helped lay to rest its once dominant role in the newly emerging technology of sucrochemistry.

Chapter 9

Sucrochemicals: Some General Issues

Having already examined the properties and technical routes toward sucrochemical production, in this chapter some of the general issues will be discussed that underline the potential for large-scale development in this industry. This serves as a prelude to the analysis of Tate and Lyle Ltd (the leading TNC in this field), which follows in the next chapter. The first issue considered is the production of ethanol. This subject is not dealt with elsewhere in the study because its terms of reference specifically exclude this and leave it to be studied as part of the "technological impact assessment of an alternative fuel system" in this project. This approach presumes that the production of ethanol for use as a fuel extender will be the principal economic application of this product. The focus of the present study, however, is on the directed synthesis of sucrose to produce other chemicals of greater worth.

Fermentation Ethanol

As indicated, the fermentation of sugarcane juice or molasses to produce ethanol, although employing no new technology, is a possible route to the chemical industry. Fermentation ethanol is an organic chemical with four major applications: the production of potable alcoholic beverages, for use as an intermediate chemical, for use as feedstock to produce other chemicals, and for use as fuel extender.

At present, the major uses of ethanol are conversion to alcoholic beverages, to act as a chemical solvent, to serve as a gasolene extender, and for conversion into other chemicals. Although traditionally the production of alcoholic beverages has dominated, increasingly, in the wake of the fuel crisis, its industrial use as a gasolene extender has grown rapidly. (World production of ethanol is in excess of 3×10^6 t (1×10^9 gal). About 52% of this is estimated to be fermentation ethanol and the remainder is synthetic ethanol (see World Bank 1980).)

When used as a *solvent* ethanol finds its principal uses in the production of toiletries and cosmetics, detergents, paints and varnishes, disinfectants, processed foods, drug manufacture and pharmaceuticals, surface coatings, etc. Fermentation ethanol is usually preferred to its synthetic counterpart when used in potable products or on the body, e.g., toiletries, and because of this preference it is able to command a premium price over its synthetic competitor (World Bank 1980:9). As a *fuel extender* ethanol has three potential uses: boiler fuel, diesel substitute, and as a gasolene substitute.

As a diesel substitute, there are a number of technical drawbacks that limit its use, although as a boiler fuel it is thought to be an inferior use of what is deemed to be a superior liquid fuel. Its major fuel application, therefore, is as a gasolene extender, where it has demonstrated superior characteristics. Because of these characteristics it is felt that "its unique physical/chemical properties increase ethanol's value, beyond its heating value, as gasolene sustitute" (World Bank 1980:iii). (These characteristics improve combustion efficiency, octane ratings, and engine performance in starting, carburation, and emissions.) Brazil is the leading country in the production of ethanol from sugarcane for this purpose. In that country, 100% alcohol-powered cars were approved for sale in 1982. Total output of ethanol has increased from 3.4×10^9 L in the crop year 1979–80 to a projected output of 1.0×10^{10} L for the crop year 1984–85. The U.S. has also encouraged the development of fermentation ethanol, using corn, through a system of federal and state taxes. The result is that domestic sales of gasohol that contains 10% fermentation ethanol in the mixture have increased from 0.8×10^6 gal in 1981 to an estimated 4.2×10^9 gal in 1983.

Brazil has been leading in the development and exporting of this technology to the rest of the world including the U.S., which is using other biomass sources particularly maize for this purpose and is industriously trying to catch up on Brazil's technological lead. It might be noted also that Brazil is using other starch sources as well in the production of fermentation ethanol, e.g., cassava. As a result of the growth of fermentation ethanol output, this sector has been playing an increasingly important role in the sugar market. Thus, if the price ratio between molasses and potable alcohol changes significantly, it affects the profitability of ethanol sales. Brazil, therefore, which is the leading exporter of fermentation ethanol (1×10^9 L during the crop year 1983–84), virtually ceased exporting molasses in 1982 when the price ratio favoured fermentation alcohol. When the reverse occurred sales of molasses were resumed. The same effect also exists between HFCS and the U.S. corn wet-milling ethanol sector as noted in Part I.

When used as a *chemical feedstock*, fermentation ethanol has first to be converted into ethylene. Approximately 1.7 lb of ethanol are required to produce 1 lb of ethylene. The theoretical conversion ratio of sugar into ethanol is 51% and in practice it is claimed that 3.7 lb of fermentable sugars are needed to produce 1 lb of ethylene (Vlitos and Parker 1981:38). In the petroleum industry, the primary products of crude oil are fuel oil and petrol. The refinement of petroleum by means of catalytic cracking produces ethylene, propylene, and C4 hydrocarbons (butane, butylenes, butadiene) in quantities determined by the throughput and process conditions. The ethylene produced in this way is followed by conversion into ethanol and finally production of the chemical product from ethanol either by dehydrogenation or by oxidation. Ethylene is the most important intermediate product in the petrochemical industry, although fermentation ethanol is more economical for products involving oxidation and dehydrogenation. The last two processes give ethanol a higher value than ethylene, whereas for the first the opposite holds true. All the ethanol conversion processes currently in use are designed for small-scale operations, compared with the tremendously large-scale plants using ethylene-based processes and reaping considerable economies of scale.

Because of the factors identified above, any major substitution of petroleum products would depend on the economic relationships that exist between fermentation ethanol-derived ethylene and petroleum-derived ethylene. The inflationary increase in petroleum prices has brought the question of its substitution by cheaper raw materials to the fore. But as the World Bank (1980:45–46) study quoted earlier concludes:

> Among the technologies currently available, ethylene production from biomass ethanol is unlikely to be competitive with petroleum derived ethylene until the crude price of oil reaches $40–45 per barrel (assuming an economic cost of sugar-cane as $10–12 per ton). It is, therefore, unlikely that large-scale substitution of petroleum derivatives (e.g. naphtha or ethane) for the production of petro-chemical products based on ethylene as an intermediate, can be justified on economic grounds in the immediate future. This conclusion could change in case petroleum prices rise much faster than projected by the World Bank, or new technologies and catalysts are developed to reduce the cost of ethylene production from ethanol. Many chemical firms are working on the latter issue and it is possible that ethanol use in the chemical industry would become economic in the next 5–10 years.

Another estimate (Vlitos and Parker 1981:38) is that:

> . . .without allowing for processing or capital costs, at the current price of ethylene (24 cents per lb.) sugar would have to be available at 6 cents per lb. for the process to become economically feasible.

Or, alternatively, it has been claimed (Parker 1979a,b):

> . . .allowing for capital and production costs, it has been estimated that for ethylene derived from fermentation ethanol to be competitive at current prices, the fermentable sugars would have to cost no more than 1 cent per lb. Conversely ethylene prices would have to reach 36 cents per lb. equivalent to oil at around $45 per barrel.

As indicated in Chapter 7, microbial conversion processes are nonspecific, in the sense that any carbohydrate source can be used. It is this that explains the frequent references to this product as "biomass alcohol," "fermentation alcohol," and so on. Although the conversion process is nonspecific, sucrose, however, has two distinct advantages over other carbohydrate sources. One of these is that its carbohydrate content is already in the form of fermentable simple sugar. The other is that one of its by-products (bagasse) can be used to fuel the factories that process it. Sucrose production from the sugarcane plant is energy self-sufficient. This is not the case with starches. Furthermore, because of their greater molecular complexity starches have to be broken down first into simpler sugars. This, therefore, adds a further process step, thereby raising processing costs. It should be reported that efforts are being made to reduce these costs by more scientific use of the by-products of other starches. In the case of maize, the higher level of by-product utilization that is achieved in the U.S. corn wet-milling industry has already been noted.

The advantages that sugar has in relation to other carbohydrate sources also exist in relation to other forms of biomass, e.g., cellulosic materials. Indeed, it has been pointed out that the advantages here are greater because the cellulosic materials have a far more complex molecular structure than the starches and have to be converted to fermentable sugars by the complex and costly process of acid hydrolysis. Furthermore, the alcohol conversion efficiency factor for these materials is lower than is the case with sucrose.

Although, as pointed out earlier, the technology of fermentable alcohol production is old and well established, there have been significant improvements in this area in recent years. This was noted when the production of HFCS was considered. One example of these improvements is the use of continuous as compared to batch fermentation processes in distillation.

It is claimed that, as a result, the alcohol yield has risen from the usual 8–10% to as much as 12%. Another very good example is the introduction in the distilleries of the heat recovery designs that have been successfully used in other manufacturing areas to improve energy efficiency and save on costs. The general picture, therefore, is of significant incremental improvements being made to a long and well established technology, and these are enhancing the competitive position of fermentation alcohol.

Whether the improvements in fermentation technology will eventually yield a competitive ethylene production from fermentation ethanol remains to be seen. The fact that it is essentially a well established and old technology would also seem to rule it out of our general purview. Nevertheless, the issues associated with the production of fermentation ethanol cannot be ignored in a study such as this. One good reason is that the discussion so far points clearly to the fact that the effective competition to sucrochemicals is petrochemicals. Although in market systems it would be expected that in the long run the competitive price relation between the two classes of chemicals will determine where profitable investments will be made, to arrive at this position one has to take into account a number of factors other than price. Particularly when, as is frequently the case, the price quoted is the price per unit of ethylene derived from two alternative sources and based on standardized factory models.

If we look at Fig. 4, we can easily see the chemicals that can be produced from an ethanol feedstock. The wide range of chemicals presented there reinforces the observation that sucrochemicals as a class of products would have to substantially displace the petroleum–natural gas–coal based chemical industries now in existence. Insofar as the chemical industry, however, is predominantly oriented toward the petroleum industry, which has a high capital intensity and a vast and costly worldwide network of production/research/marketing facilities, these investments cannot be simply wished away. The petroleum companies can be confidently expected to resist any serious inroads into their markets. One important advantage that these companies possess and should never be underestimated is a flexible marketing structure. This is based on the consideration that the primary products derived from crude oil are fuel oil and petrol. Ethylene-, propylene-, and butane-related products are essentially by-products whose output is determined by the throughput and process conditions of the refinery. This permits the companies to be flexible in the production of particular chemicals and to apportion costs and charge prices to their various products in a way that would protect any threatened product while optimizing overall profitability from their operations (Parker 1979a,b):

> The pricing policy of the industry will understandably be to spread increased raw materials costs over primary and by-products in such a way as to maintain their balance. Inevitably, therefore, significant competition in a

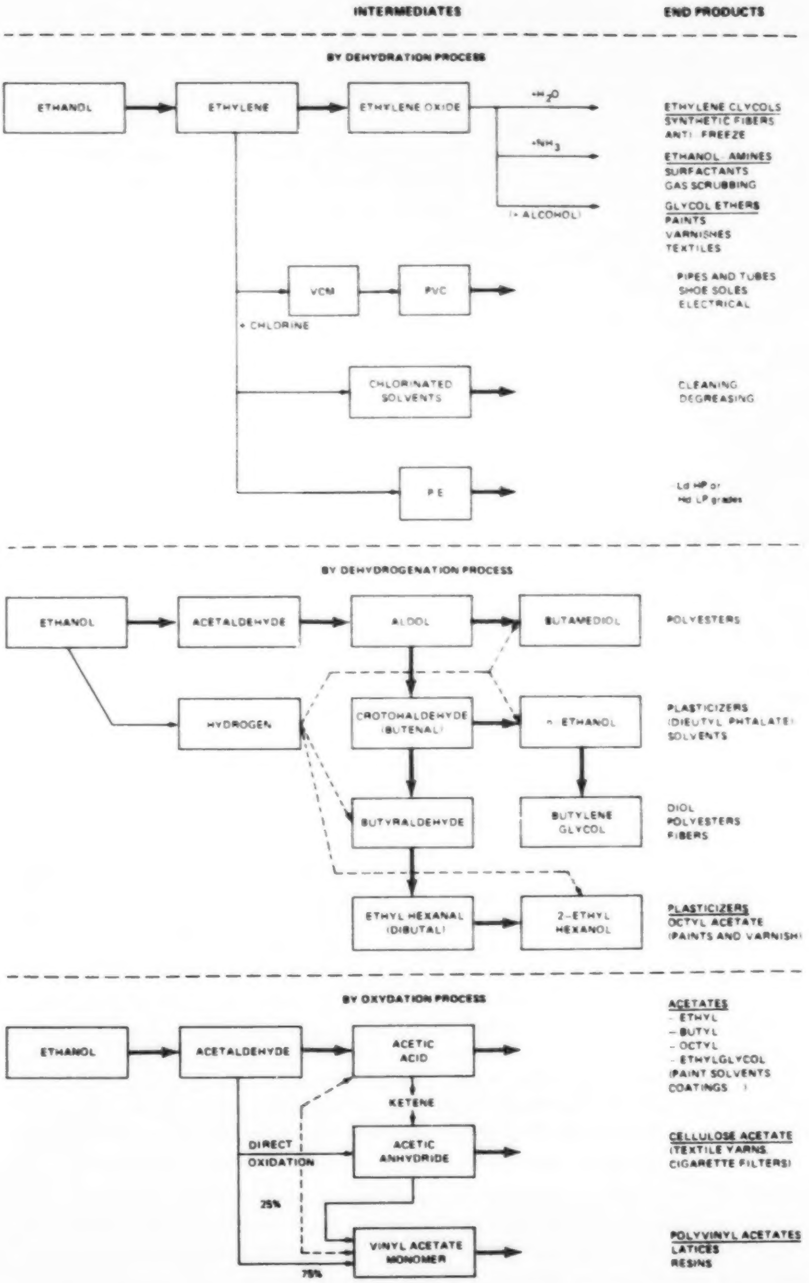
INTERMEDIATES
END PRODUCTS
BY DEHYDRATION PROCESS
ETHANOL
ETHYLENE
ETHYLENE OXIDE
+H$_2$O
+NH$_3$
(+ ALCOHOL)
ETHYLENE CLYCOLS
SYNTHETIC FIBERS
ANTI FREEZE
ETHANOL AMINES
SURFACTANTS
GAS SCRUBBING
GLYCOL ETHERS
PAINTS
VARNISHES
TEXTILES
VCM
PVC
+ CHLORINE
PIPES AND TUBES
SHOE SOLES
ELECTRICAL
CHLORINATED SOLVENTS
CLEANING
DEGREASING
PE
Ld HP or
Hd LP grades
BY DEHYDROGENATION PROCESS
ETHANOL
ACETALDEHYDE
ALDOL
BUTAMEDIOL
POLYESTERS
HYDROGEN
CROTOHALDEHYDE (BUTENAL)
n ETHANOL
PLASTICIZERS
(DIEUTYL PHTALATE)
SOLVENTS
BUTYRALDEHYDE
BUTYLENE GLYCOL
DIOL
POLYESTERS
FIBERS
ETHYL HEXANAL (DIBUTAL)
2-ETHYL HEXANOL
PLASTICIZERS
OCTYL ACETATE
(PAINTS AND VARNISH)
BY OXYDATION PROCESS
ETHANOL
ACETALDEHYDE
ACETIC ACID
KETENE
ACETIC ANHYDRIDE
DIRECT
OXIDATION
25%
75%
VINYL ACETATE MONOMER
ACETATES
- ETHYL
- BUTYL
- OCTYL
- ETHYLGLYCOL
(PAINT SOLVENTS
COATINGS)
CELLULOSE ACETATE
(TEXTILE YARNS
CIGARETTE FILTERS)
POLYVINYL ACETATES
LATICES
RESINS

Fig. 4. Alcohol from biomass: production of chemicals from ethanol by major process routes. Source: World Bank (1980).

> by-product outlet will be countered by a price reduction to restore this balance. In this sense, raw material prices will not reflect directly increased oil costs.

Such pricing mechanisms constitute a formidable advantage because they reduce the effectiveness of one method of product diffusion, which is to capture segmented markets in a sequential way (this point was discussed in Chapter 5 in the case of HFCS market penetration). The cost of penetrating markets on a broad front will be very high, particularly when the heavy capitalization of the petroleum industry is taken into account. By contrast, the infrastructure of the sugar industry is perhaps not developed enough to launch a marketing offensive on the scale required.

One further aspect of market penetration that should be mentioned here is that the user industry often finds uses for chemicals that the producer may not have anticipated. There can, therefore, be a cumulative virtual circle of initial market penetration, followed by uses being found by the initial user that the innovation may not have anticipated, which leads to further demands for the product and so on. But to achieve these, the market has to be first penetrated. One successful experience of a sucrose-based chemical has been summed up this way (Vlitos 1977:343): "When you have a chemical you need to find a use for it. The sugar industry is not the best suited to find the applications. These have to be developed by the 'user' industry."

As the author goes on to point out, in the case of its surfactant, Tate and Lyle Ltd found that although it was produced to service one need, the actual use in industry has resulted in "over 15 different potential applications because we found customers, who, in turn, found uses for the product we never even thought of" (Vlitos 1977:343).

Because the petroleum and chemical industries are often considered strategic industries in terms of national security, an increasing role of governments, over and above that which they normally play, can be expected in determining the lines of future energy development. This would be of course an important countervailing force to the power of the petroleum companies. The lines that any government would pursue would depend on the resource, national security, and social and political objectives of the government. Thus, in the case of Brazil, government support for its gasohol program in the absence of significant quantities of indigenous oil deposits has been decisive in the orientation of both its energy and chemical industries. Similarly, a strategic commitment to nuclear energy has been important in the development of Soviet industry. One index of the significance of the observation made here is that the petroleum companies themselves have been active in the acquisition of technical rights, R&D facilities, as well as production facilities in the "new" energy technologies, as part of their strategic responses to the new technologies. (See the statement by the Executive Director, U.N. Centre on Transnational Corporations to the U.N. Conference on New and Renewable Sources of Energy, Nairobi, Kenya, August 1981.)

In addition to the high cost of market penetration for new chemical feedstocks, one must also consider the formidable barrier of expertise to be overcome. The orientation of the chemical industry toward petroleum feedstocks has inevitably influenced the pattern of training and skills within the present chemical labour force. Universities, colleges, and other training institutions have geared their programs to the production of these skills, and their conversion to sucrochemistry cannot be contemplated as an overnight affair. Furthermore, the petroleum companies have a reputation for high levels of remuneration and material rewards. This reputation not only encourages the flow of persons into petrochemistry, but it also raises the cost of developing a skills base in sucrochemistry.

If the high cost of market penetration and development of a skills base in sucrochemistry are not enough obstacles in themselves, one must also take into account the cost of developing the new technologies. This cost encompasses the long gestation period while research takes place, the subsequent period of development of the new product or process, then on to pilot testing and the establishment of production facilities. In the early days, some of these costs were borne "collectively" by the sugar producers through the Sugar Research Foundation, but the shift of the centre of research to Tate and Lyle Ltd has put a lot of these costs of development on to this TNC, and the results of this will be discussed at some length in the following chapter.

Replenishability and Environment

Two major advantages favouring sucrochemistry derive from the fact that sucrose is an agricultural product. One of these has been referred to often enough, i.e., sugar is a replenishable resource, whereas petroleum is a finite resource. One should not, however, overstate the finite characteristics of petroleum. The known global reserves of oil and natural gas exceed the amount of hydrocarbons so far extracted. Deposits of coal are projected at being able to meet current extraction rates for another three centuries whereas shale oil and tar sands have not been exploited in significant quantities thus far.

Furthermore, it should be pointed out that new reserves are being continuously discovered, but the huge rise in the price of this product has stimulated increasing concern over energy efficiency and a search for alternatives including, as has been mentioned, ethanol. There will, however, always be an upward pressure on prices exerted by the inelasticity of supply. Although this can be countered by improved recoveries, etc., it is a pressure that over the long run cannot be ignored. As a replenishable product, sugarcane does not face the same difficulty, particularly as in all the discussions so far it is not expected that sucrochemicals will lead to vast increases in acreage committed to sugarcane cultivation, except possibly in the case of fuel extenders, which falls outside the direct purview of this study. (To replace 10% of U.S. current annual consumption of gasolene by alcohol would require about 2.5 times the world sugar output.) The nonfood uses of cane and beet sugar are seen as being compensated for by increased output of alternative sweeteners. As a consequence the impact on agricultural land availability is not thought to be particularly forbidding at this stage.

The second major advantage is the environmental impact. Most sucrochemicals are biodegradable, nontoxic, noncarcinogenic, etc. This provides for a favourable environmental impact. The major environmental problems are posed when alcohol is fermented and distilled. The major by-products here are carbon dioxide, fusel oils, and stillage. The first of these is normally discharged into the atmosphere. Fusel oils, about 5 kg/1000 L of ethanol can be collected and further utilized. Stillage is produced in large amounts (about 10–13 times the volume of alcohol produced). Because this has potential use as animal feed and fertilizer, it is likely that disposal of this can take place economically. As Vlitos (1979b:E14) sums it up: "In general chemicals derived from carbohydrates or other biomass products are more amenable to degradation in the biosphere, and hence present less of an environmental hazard, than do petrochemicals, particularly the intransigent aromatic compounds."

In light of the considerations raised so far there is merit in Parker's division of the potential sucrochemicals markets into two broad categories (Parker 1979a,b). These are the high-valued products produced in small volume and the low-valued products produced in large volume. In the former market, the chemical process is the important element of cost and selling price. What is being sold are sophisticated chemical processes rather than the raw material sucrose. Examples of such products that are expensive to develop are systemic fungicides and certain pharmaceuticals. In the latter market, sucrose is being sold as a cheap chemical and the processes used are not costly. Examples of these are the sucroglycerides, animal feed additives, resins, alcohol, and plasticizers. This market distinction, by showing an appreciation of the relation of process to raw material cost, allows some order/ranking to be imposed on the range of over 10 000 chemicals and chemical intermediates that sugar can produce.

Although at present over 10 000 chemicals can be produced from sucrose, the products that can be produced fall within certain broad market categories (Parker 1979a,b): (a) foods, (b) feeds, (c) fuels, (d) explosives, (e) elastomers, (f) lubricants, (g) solvents, (h) soil conditioners, (i) fibres, (j) adhesives, (k) paper, (l) pesticides, (m) plasticizers, (n) plastics, (o) surface coatings, (p) surfactants, (q) medicines/pharmaceuticals, and (r) cosmetics.

The main lines of immediate exploitation of these markets will be discussed more fully in the study of Tate and Lyle Ltd in the next chapter. At the moment, what can be observed is that the most likely markets to be developed are those listed as (a), (b), (m), (n), (p), (q), and (r). This list deliberately excludes item (c) (fuels) as it does not fall within the purview of this study. At present, the largest nonfood outlet for sucrose is polyurethane resins. The market is growing rapidly (at about 12% per year), and current U.S. production is 0.75×10^9 lb. To produce this quantity requires about 50 000 t of sucrose. The use of sucrose monoesters world wide is currently estimated at 12 000 t. As a result, although the industrial potential of sucrose is considered to be great, only about 100 000 t is used in this way, which is a very small fraction of current world output of this product. The reality is that apart from the fairly general consumption of molasses in animal feeds, potable alcohol fermentation from sugarcane juice and molasses, other microbial routes that can compete with synthetic routes (e.g., citric acid), and recently the gasohol programs, the industrial use of sucrose has not lived up to its promise. As the then Chief Executive, Group Research and Development, Tate and Lyle Ltd, pointed out the difficulties (Vlitos 1977:340):

> Sucrose can be chemically modified or reacted to yield a wide variety of products. Generally these products have not found markets either because (i) the costs of production were too high relative to existing petro-chemically derived product, or (ii) insufficient development work had been done to indicate suitable applications, or (iii) the chemical industry. . .was and still is orientated to petro-chemical 'feedstocks' rather than to sucrose. There was

> no platform or infrastructure either within the sugar industry or within the chemical industry to ensure commercialisation of sugar-based chemicals. Nor was there enough 'patient' money available to invest in a very long term venture. The sugar industry was not prepared to invest the sums required to launch new chemical products, especially when the initial economics looked unfavourable. A long time lag between the research work and commercialisation inhibited investment. The chemical industry itself was not prepared to invest very much on seeking alternative feedstuffs when petro-chemicals were so abundant and cheap.

In conclusion, although the inflation of petroleum/natural gas prices has altered to the disadvantage of petroleum, i.e., its price relative to that of other sources of energy and chemicals, there is as yet not a sufficient alteration as to make the cost advantages of these alternatives demonstrably clear. In any case, the price structure of the petroleum industry together with the strategic and political significance of petroleum and chemical products would not allow this matter to be resolved simply in the market place — even though the price/cost consideration will be important to the eventual outcome. Because of this, it is my belief that the future of sucrochemicals is bound up with its ability to win one or more government's support for it on the basis of social, national, as well as market considerations. It is only national governments that can yield a sufficient countervailing power against the TNCs. The sugar companies alone cannot. This conclusion should be kept in mind as we consider in the next chapter the gains and difficulties confronting the world's leading sucrochemicals firm, Tate and Lyle Ltd.

Chapter 10

Sucrochemicals and Transnational Enterprise

The Importance of Tate and Lyle Ltd

Despite recent decisions to alter drastically its focus of R&D, Tate and Lyle Ltd, the British-owned TNC, has been, for the past decade and more, easily the leading force in the drive to develop sucrochemicals. Because of its unquestioned leadership in this field, its operations are probably the single most important index of the likely impact of technological change in the area of sucrochemicals in the near to medium term, if not over the long term. Other studies on monitoring technological opportunities reinforce the importance that is attached here to the monitoring of the leading enterprise. Thus, Utterback and Brown (1972:14) observe

> When a technical field or product area is undergoing rapid change, or in cases where product life cycles are relatively short, it would prove worthwhile to devote more of the forecasting effort to monitoring resource commitments.

It seems self-evident that the commitment of resources by an organization, let alone a commercial one, to new product development and new technology should be a fruitful indicator of the commercial prospects of the new product or technology. This point of view is also reinforced, insofar as this commitment is first made by a very small number of firms, and in this instance only one, as it is far easier to monitor this than it would be to monitor a large assortment of patents, technical papers, product and technology specifications, research in progress, etc. The leading enterprise, therefore, can be seen as acting as a guide through this diverse array of documentation. Of course, the leading enterprises can make and have made serious misjudgments in the past, so that this approach, although useful, still has to be pursued with great care and caution because of the known hazards of forecasting technological opportunities and their commercial impacts.

Tate and Lyle Ltd is the world's largest privately owned sugar company. It is a U.K.-based transnational, which in 1983 embraced 53 subsidiary companies, of which 19 were based in the U.K. and 34 overseas. In addition, there were 11 associated companies, "other" investments in four corporations, and a joint venture with one. One of its subsidiaries in Canada (Redpath Industries) had six further subsidiary operations. The company operates in all the continents with a total turnover of about 2 billion pounds sterling (GBP1.44 = US$1). Its trading sectors operating bases are agribusiness; bulk liquid storage, cane-sugar production, and refining; cereal sweeteners and starches; commodity trading world wide; insurance; malting; molasses trading, storage, and distribution world wide; warehousing, packaging, and distribution; and other miscellaneous activities. Details on the turnover and the composition of assets of these 10 trading sectors and operating bases are shown in Tables 38 and 39.

Because of its substantial trading in sugar, molasses, and other agricultural products whose prices are very volatile, the composition of assets and turnover shows wide swings from year to year. Unfortunately, because of substantial accounting changes in the valuation and structure of its assets the data on these sectors and categories are not available for a long time series. It has been possible, however, from a study of recent company reports and accounts to pick up the main threads of both the continuities and changes in its major operations.

Table 38. Tate and Lyle Ltd: analysis of turnover 1980–82 (GBP million).[a]

	Turnover			
Trading sectors and operating bases	1980	1981	1982	1983
Agribusiness	29.4	38.0	20.1	31.4
Bulk liquid storage	9.5	8.8	10.1	10.8
Cane sugar production and refining				
United Kingdom	374.9	350.1	396.7	449.7
Canada	69.1	106.9	74.4	90.3
USA	77.9	133.3	125.7	148.9
Belize	14.0	15.8	10.0	15.9
Zimbabwe	18.1	26.7	28.7	26.5
Total	554.0	632.8	635.5	731.3
Cereal sweetener and starches				
Canada	—	0.4	3.8	7.2
Europe	38.4	43.5	47.7	55.1
Total	38.4	43.9	51.5	62.3
Commodity trading world-wide				
Sugar	431.0	1105.5	904.1	615.2
Other	54.3	41.5	55.1	49.3
Total	485.3	1147.0	959.2	664.5
Insurance	—	—	—	—
Malting				
United Kingdom	19.6	18.4	24.9	25.7
Molasses trading, storage, and distribution				
World wide	224.4	246.9	219.1	220.1
Warehousing, packaging, and distribution				
United Kingdom	28.4	27.4	29.1	34.7
Nigeria	20.3	27.7	24.1	15.2
Total	48.7	55.1	53.2	49.9
Other activities	91.8	73.4	58.9	69.9
Total	1499.1	2264.3	2032.5	1865.9

Source: Tate and Lyle Ltd, Annual Reports, 1981–83.

[a](GBP = pounds sterling) GBP1.44 = US$1.

The wide swings in the value of the TNC's assets can, however, be seen from the data in Table 39. Thus, for 1981–82, the average value of assets in cane sugar production and refining was more than GBP150 million compared with about half that value in 1980 (GBP79.5 million).

This made cane sugar production and refining the largest trading sector in terms of assets employed in 1981–82, but in 1980, it ranked second after commodity trading world wide. Similarly, the valuation of assets devoted to commodity trading world wide fell from GBP83.5 million in 1980 to less than half that amount (GBP38.2 million) in 1981 and rose to GBP49.6 million in 1982. These wide variations in asset structure reflect the deep involvement of the company in the production, processing, storage, and trading of agricultural commodities, especially sugar and other sweeteners. As will be shown later, this involvement has prompted the search for a chemical industry based on sugar, but, in the end, the very structure of the company's operations raised doubts about its capacity to pursue this line of endeavour successfully.

The wide variations in assets employed are inevitably reflected in the company's turnover, as can be seen from the data in Table 38; although the swings here are either in different directions or reduced on comparison. Thus, the near doubling of assets in cane sugar production and refining between 1980 and 1981 is reflected in a 14% increase in turnover. Commodity trading world wide grew by a factor of 2.4 between 1980 and 1981, whereas assets employed fell by a factor of 2.2. Agribusiness turnover also grew by one-third between 1980 and 1981, and assets employed grew by a factor of 2.3. The turnover data reveal that the cane sugar production and refining is still the largest source of company sales. Currently, it averages about 40% of these, and, when added to sugar trading world wide, it accounts for more than two-thirds of total sales.

Until 1982, research and development activities of Tate and Lyle Ltd, along with its new ventures, were located in its New Developments Division. Within this division there is the Talres Development Company, a wholly owned subsidiary that forms the bridge between research and commercialization. The TNC also maintains substantial research facilities at Reading University. Although

Table 39. Tate and Lyle Ltd: analysis of assets employed, 1980–82 (GBP million).[a]

	1980	1981	1982
Agribusiness	2.3	6.5	3.5
Bulk liquid storage	19.7	19.7	22.3
Cane sugar production and refining	79.5	157.4	148.7
Cereal sweeteners and starches	18.4	28.5	33.8
Commodity trading world wide	83.5	38.2	49.6
Insurance	8.5	9.5	14.1
Malting	14.9	14.9	17.9
Molasses trading, storage, and distribution	23.8	39.1	45.1
Warehousing, packaging, and distribution	11.4	10.9	12.0
Other activities	31.0	21.9	14.6
Total operating assets	293.3	346.6	361.6
Specialty chemicals	13.5	7.3	0.8
Central	(12.2)	6.5	14.4
Total	294.6	360.4	376.8

Source: Tate and Lyle Ltd, Annual Reports, 1980–82.

[a] Changes in the valuation and structure of assets in 1981 restrict the availability of comparative data to 1980–82. ((GBP = pounds sterling) GBP1.44 = US$1.)

R&D activities will be discussed in the next section, it should be noted at this stage that the speciality chemicals activities in the company were located in this division. The Chemicals Division of the company was, until 1981, a major part of its structure and formed one of the four major divisions of the TNC, the others being the U.K. Division, International Division, and the North America Division. Since 1982, the division has been removed.

By studying the accounts and reports of Tate and Lyle Ltd, it is very evident that a decision was taken in the early 1970s to reduce substantially the company's involvement in sugar and to find a more diversified production base. The assets and turnover structure shown in Tables 38 and 39, therefore, is the product of more than a decade of diversification of the corporation's structure. The TNC's base in sugar was of course the launching pad into other operations. In 1976, the Chairman's Report on the corporation's activities stated as follows (Tate and Lyle Ltd 1976:9):

> Tate and Lyle's business is to supply, trade and handle commodities and to provide the services for handling other people's goods. The group has used its strong international base in sugar to expand into many other related businesses, resulting in a substantial presence in the worldwide markets for processing, trading and handling many goods, feedstuffs, fuels and chemicals.

The pace of diversification of the corporation's structure can be traced from the fact that whereas in 1976 the major trading sectors were sugar, starch, commodity trading world wide, bulk liquid storage, shipping, warehousing and distribution, and engineering and consultancy (by 1981 the last item was well established as an agribusiness complex), malting, insurance, and specialty chemicals were added to its list of activities and the shipping fleet of the TNC had been dissolved. The diversification into North America was also rapid — leading to the creation of a whole new division to cover these activities. In addition, the company withdrew from owning plantations overseas and moved into the more profitable and less risky business of consultancy and management services in this area. The result of these changes to date is neatly summed up by the Chairman of the Board (Tate and Lyle Ltd 1983:4):

> As important as the improvement in the profit figures is the change in the quality of the Group's earnings over recent years. Five years ago more than half the Group's profits were generated by commodity trading. This year over 75% of pre-tax profits were derived from our manufacturing businesses in the UK and North America.

The Group's Managing Director also pointed out the following in the same report (Tate and Lyle Ltd 1983:6):

> Over the last five years the Group's primary objective has been to improve its profitability by rationalising its operations into businesses in which it has a long-term involvement and by improving the productivity of these businesses. The first stage of the recovery programme is now virtually complete. Loss-making units have either been brought back to profit, sold or closed. The need for continued improvement in productivity continues.

The diversification thrust of Tate and Lyle Ltd had been brought on by a number of major developments confronting the TNC. One of those has been the rapid and unfavourable changes in the structure of the world's sweetener industry. This was discussed at some length in Part I, and the points of major importance to note are the extreme uncertainty of sugar prices; the rise of beet sugar production and consumption, particularly in Europe; the growth of the HFCS industry; the slow growth of global consumption of sucrose; and the drive for self-sufficiency in sweeteners among the developing countries, whose consumption of sugar is rising.

A second development of major significance was the ending of the CSA and the entry of the U.K. into the EEC. Tate and Lyle Ltd had built its sugar refining operations on sugarcane cultivation in the U.K.'s ex-colonies and the preferential access that this sugar had into the U.K. market. With the U.K.'s entry into the EEC, this came to an end and was replaced from the TNC's standpoint with the less favourable EEC–ACP Agreement. In addition, the sweetener regime of the EEC, and in particular its strong support for European beet sugar, has created major obstacles for a company traditionally based on cane sugar production and refining. The effect of these developments has been a drastic rationalization of sugar refining operations in the company; occasioned by the large decrease in the available U.K. market. Thus, in 1981, the company estimated the U.K. market at 2.3×10^6 t of sugar. Of this total, domestic beet production in the U.K. would have absorbed 1.1×10^6 t and imports of white sugars from the EEC, 0.15×10^6 t. The total supply of beet sugar would therefore, have been 1.25×10^6 t, leaving a residual of 1.05×10^6 t for cane sugar. Meanwhile, Tate and Lyle Ltd's refining capacity was 1.34×10^6 t, which is an overcapacity of about 27%. In a recent report, the company listed four causes of the sugar refining crisis confronting it: a collapse of export margins, an increase in U.K. beet sugar production, a contraction of the U.K. sugar market, and the importation of white sugar from the EEC.

The report then goes on to state (Tate and Lyle Ltd 1980a:13):

> Because the cane sugar refining margin is so much lower than that for beet processing, these four factors have forced Tate and Lyle refineries to seek to reduce refining capacity in line with shrinking demand for its products.

A third development leading to the diversification strategy was the reduced control the TNC could exercise over its investments in overseas sugarcane growing areas. A number of familiar political and social factors are associated with this development and so do not require repeating here. A fourth factor is that over the years of contact with sugar cultivation and refining the company had developed a wealth of expertise in related activities, e.g., shipping, bulk storage, engineering and cultivation consultancy capability in tropical agriculture, molasses handling, and so on. It was, therefore, logical that in a period of crisis a constructive response to protecting the TNC's interests would have been to exploit the skills capabilities that it had developed over the years. A fifth factor was the TNC's decision to diversify into the politically less risky environment of North America where it could exploit its expertise in sweeteners and where Commonwealth relations with Canada provided a useful point of departure. The final and perhaps most decisive consideration, certainly in terms of timing the transition to other activities, was the inflation of oil prices and reported scarcities of this product. This consideration more than any had specifically intensified the search for sucrochemicals, even though its impact on the company's activities has been far more wide ranging.

Table 40. Tate and Lyle Ltd: research and development allocations.

Year	GBP million[a]
1977	3.3
1978	2.9
1979	3.5
1980	5.4
1981	6.8
1982	4.1
1983	3.1

Source: Tate and Lyle Ltd, Reports and Accounts (various issues).

[a](GBP = pounds sterling) GBP1.44 = US$1.

The data in Table 40 show the TNC's accounting deductions from profit for R&D expenditures and specialty chemicals over the period 1977–83. These allocations are deducted from profits in the year of their expenditure. In the case of joint ventures, the figures are net of the partner's contribution.

Tate and Lyle Ltd R&D Activities

In this section, R&D activities of Tate and Lyle Ltd will be highlighted in the general area of our interest in an effort to pinpoint the potential growth points over the near to medium term. Emphasis will be placed on the immediate precommercialization activities. The analysis, however, does not adequately treat the TNC's activities connected with the improvement of cane sugar cultivation and processing in which the TNC has made important technical innovations recently.

Degradation of Sucrose

The limitations of the degradation reactions of sucrose have already been discussed at some length as a route toward the production of chemicals. Much of the literature cited in this context, e.g., Parker, Hickson, Vlitos, Hough, and Righelato, comes from scientists and scientific managers associated with Tate and Lyle Ltd's laboratories. The only significant research in this area is the effort by Tate and Lyle Ltd to improve yields of mannitol and sorbitol. In many ways it can be said that Tate and Lyle Ltd's R&D work in specialty chemicals has been founded on the explicit recognition of the exhaustion of the possibilities of this route, and this encouraged its willingness to commit resources to the pursuit of the development of other routes to chemical production from sucrose.

Sucroesters

Over the past decade, work on the production of sucroesters constituted one of the major areas of Tate and Lyle Ltd's R&D efforts. This led to the development of significant products that only a few years ago had seemed to reach the commercialization and immediate precommercialization stage. The main effort here has been directed at discovering commercial processes for the production of sucroesters for use in detergents, as food additives, in cosmetic and skin care products, animal feeds, and polymers. The outstanding technological opportunity so far has been the breakthrough discovery of the TAL process for producing detergents.

Tate and Lyle Ltd's work on the TAL process takes us back to the discussion in Chapter 8, where it was noted that the SRF had pioneered research in the transesterification between a trigylceride and sucrose, using DMF as a solvent. The trigylceride used was tallow and followed the initiative of the State of Nebraska in the U.S. in asking the Foundation for its help in finding uses for its surplus animal fats. As noted in that chapter, the discovery of solvents such as DMF, which made this transesterification process possible, although a critical breakthrough, was nevertheless expensive because of the high costs of the solvents. In addition to this, it should be pointed out that the Foundation's process of transesterification took place in the presence of potassium carbonate K_2CO_3, used as a catalyst at a temperature of 90° C. The process initiated an incomplete reaction that yielded a complex mixture of mono- and diglycerides and sucrose esters. The mixture also contained unreacted mixtures of sucrose and tallow. All these additional factors inevitably raised the costs of purification and analysis. Mention was also made in Chapter 8 that questions were raised about the possible toxicity of DMF. As a result, it was stipulated that if it were used in food it had to be present in less that 50 ppm.

Some of the scientists associated with this work at the SRF later joined Tate and Lyle Ltd where an effort was being made to improve upon this process to lower processing costs. This was successfully achieved when scientists in Tate and Lyle Ltd's laboratories discovered that under certain conditions sucrose would react directly with a triglyceride *in the absence of a solvent*. A surfactant was prepared by reacting the following materials: tallow 40 g (64.5%), sucrose 17 g (27.4%), and K_2CO_3 5 g (8.1%). This was a simple reaction that yielded a complex mixture with the following properties: sucrose monoester 27%, sucrose higher ester 3%, sucrose 13%, triglycerides 3%, diglycerides 9%, monoglycerides 15%, and potassium soaps 30%.

The sucrose-based detergents produced from this process have certain highly esteemed properties, for example, complete and rapid biodegradability; nontoxicity to mammals, fish, and microorganisms; low foaming, which enhances its use in automatic machines; nonirritant; nonallergenic; orthodermic; and excellent surface active, emulsification, and oil-dispersing detergent properties.

The environmental-related advantages are formidable ones particularly as the threat of accumulated detergent residues in inland waterways because of the low bacterial degradation of alkylary sulphonates was acute at the time of this discovery. Although the switch to linear alkyl sulphonates has reduced the severity of the situation, it has not entirely removed it. The product's main disadvantages are its thermal instability, its instability to strong alkalis, and its incomplete water solubility. Removing these inhibitors invariably adds to the cost of production.

It is significant to note that when reporting this pioneering work Tate and Lyle Ltd scientists remarked on the "accidental" nature of the discovery — thereby highlighting the "serendipity factor" in scientific discovery (Vlitos 1977:343):

> . . .we did not plan to fashion a new surfactant. One of our chemists was working on the general reactivity of sucrose in the absence of solvents: sucrose was reacted with tallow in the presence of potassium carbonate at 125°C.

Two features associated with this process and the product are worthy of special note. One is that the triglyceride that can be used need not be tallow. Any triglyceride, whether plant or animal can be successfully used. This of course, widens the range of useful additives (e.g., coconut oil), from the point of view of the developing countries. Second is the observation made in the previous chapter about the "user impact" on a product or a new technology. It was this same TAL process that was cited in the example to show that, although it was produced with one purpose in mind, actual industrial use had yielded up to that point 15 different potential applications that had not been contemplated at the outset.

Tate and Lyle Ltd formed under the Talres company an industrial complex at Knowsley with a 5000-t/year capacity plant to produce a variety of surfactants with different physicochemical properties. Initially, there were delays and reschedulings, and the restated aim was to expand this capacity to 22 000 t/year. In addition to its U.K. commercial operations in this area the company reported that it had entered into licencing deals with the Philippines for a 25 000-t plant using coconut oil as the triglyceride. Japan and some countries in Latin America had also shown interest. To encourage the use of this product the corporation was also able to get the end products of this process classified in Annex I of the EEC's permitted list of emulsifiers and stabilizers.

Although the detergent use of this surfactant has been the major breakthrough in this category of applications, other important developments have also taken place. In the food sector, sucrose-based surfactants have yielded the following advantages: improved surface appearance, improved wetting properties in reconstituted dried foods, improved humectancy, delayed staling properties, improved oven spring, crumb softness, increased number and regularity of gas cells making for more uniform slice, adds gluten to nonwheaten flours, and fat-sparing properties in that it spreads the fat more evenly over the flour granules permitting a good loaf to be made with less expensive shortening.

In the *cosmetics and pharmaceutical* applications sucrose-based surfactants have shown themselves to make superior skin-cleansing formulations. In addition, the products are nonallergenic, nontoxic, and completely orthodermic. In animal foods, sucrose-based surfactants produced at Tate and Lyle Ltd are thought of as improving the digestability of fat in animal foods.

In *herbicides*, preparations made from sucroesters are particularly efficient because they assist the absorption and transport of herbicides in plants. Their nontoxicity is an advantage in that these preparations also leave no persistent or toxic residues.

Chlorodeoxy Sugars

Tate and Lyle Ltd laboratories discovered early that 1′,4,6,6′-tetrachlorogalactosucrose is several hundred times sweeter than sugar. Subsequent investigations have revealed that 1′,4,6′-trichloro compounds are as much as 2000 times sweeter than sugar. Most significantly, these compounds have a pure sweet taste that experiments have established as being indistinguishable from sucrose. These processes clearly open up the possibility of a new class of low-calorie sweeteners based on sucrose. Currently, toxicological tests are under way as part of a major precommercialization effort. As Hickson (1979) points out: "These chlorinated sucroses really could qualify as the new generation of artificial supersweeteners — that is if they can pass the necessary rigid tests for health safety."

It should be pointed out that 1′,2,6,6′-tetrachlorotetradeoxymannosucrose is an exceedingly bitter substance, having more than twice the bitterness of octaacetate and, therefore, a major challenger to the markets for denaturants. Closely related also are the 6-chlorodeoxymonosaccharides, which are being studied for their medical uses. Table 41 indicates the relative sweetness of the chlorodeoxysucroses.

Microbial Conversion

Monitoring of Tate and Lyle Ltd's R&D work in the area of microbial conversion indicates three major significant product/process developments. The first of these is the *treatment of wastes*. As has been noted the processing of sugar yields a number of waste products, e.g., stillage. Arising out of its interest in this area Tate and Lyle Ltd has embarked upon work in the area of enzyme technology to recover saleable products from wastes. One of the directions of this work is the possible utilization of waste streams and mother liquors from sugar as a substrate for the mixed culture of microorganisms. Another area is the use of microorganisms in anaerobic fermentation to produce methane from waste-treatment processes. A third significant direction is the use of this technology to improve water-purification systems.

The second major area of technical development is the production of *microbial polysaccharides*. These products are used as gelling, thickening, and suspending agents in a wide range of applications. The market for these products is generally not large except for xantham gum, which is estimated at 50000–60000 t annually. In a joint venture with Hercules Inc. (subsequently abandoned), a company that has experience world wide in marketing water-soluble polymers, three sucrose-based microbial polysaccharides were being produced. Xanthan gum was produced under the trademark BIOZAN in three grades: food grade, standard grade (for use in general and agricultural applications), and oil drilling grade.

The xanthan gum has been described by Lock (1980:433) as

> . . .a high molecular weight, water soluble polymer, with a combination of interesting rheological properties which are maintained even at high temperatures. The gum's unusual molecular structure in which the polymer back-

Table 41. Relative sweetness of chlorodeoxysucroses.

Sucrose	1
Galactosucrose	Not sweet
1′-Chloro-1′-deoxysucrose	20
4-Chloro-4-deoxygalactosucrose	5
6-Chloro-6-deoxysucrose	Bitter
6′-Chloro-6′-deoxysucrose	20
1′,4-Dichloro-1′,4-dideoxygalactosucrose	600
1′,6′-Dichloro-1′,6′-dideoxysucrose	500
1′,4,6-Trichloro-1′,4,6-trideoxygalactosucrose	1000
1′,4,6,6′-Tetrachloro-1′,4,6,6′-tetradeoxygalactosucrose	200

Source: Khan and Forage (1979/80).

bone is protected by negatively charged side chains, promotes its use as a thickener and suspending agent in acidic, alkaline and highly saline media where other water soluble polymers might be degraded or precipitated.

The third microbial conversion effort is the production of *ethanol*. The TNC does not seek to produce ethanol per se but seeks to make innovations in the processes of ethanol production. As noted in the previous chapter, the technology of fermentation ethanol is well established. In most cases, ethanol concentrations of less that 10% v/v are produced in the space of 20-30 hours with conversion efficiencies of about 90% of the theoretical maximum of 51%. Tate and Lyle Ltd research is directed toward developing processes that can: (a) increase the concentration of ethanol and, hence, reduce distillation; and (b) reduce the costs of setting up distilleries.

The company claims that it is able to produce ethanol well in excess of 10% v/v with holding times in a continuous reactor of less than 10 hours, with no loss in conversion efficiency. This permits the installation of smaller and, hopefully, cheaper fermenters and stills, with lower capital costs generally and less energy input into the recovery of ethanol. In some publications, there are hints of a 30% alcohol concentration and of small efficient converters capable of conversion at 10 or more times faster than the normal rate (Righelato 1979:150).

The company's technological effort in this area has followed from its substantial interests in starch, sugar, and molasses. The worldwide effort at sugarcane-produced ethanol for energy in the Third World has attracted its efforts in this area. Its long history of direct contacts with sugarcane and molasses producers has no doubt given a filip to this development. As pointed out, the company has announced no plans for ethanol production of its own.

Talin Sweetener

Talin sweetener along with the remaining items briefly discussed in the following paragraphs does not fall within the ambit of sucrochemicals, but these activities are important because they indicate the hedging of the corporation. One outside threat to the sweeteners market that currently exists is the development of a safe, low-calorie sweetener. Many people who consume sugar (and those who do not) fear its calories while liking the taste. A substantial financial prize exists for whichever enterprise is able to produce a low-calorie sweetener with the taste and other acceptable properties of sucrose. The company's investment in specialty chemicals research in the chlorodeoxy sugars reflects its commitment to invest resources in this search as are its efforts to produce a sweetener from Talin, a West African plant mentioned in Chapter 7 (*Thaumatoccus danielli*). The berry of this plant is not only several times sweeter than sugarcane but it is low in calories, noncarcinogenic, and flavour enhancing.

HFCS

Although HFCS was discussed in Part I, it should be noted here in the monitoring of Tate and Lyle Ltd's activities that along with Talin sweetener and the chlorodeoxy sugars, activity in the HFCS area indicates the integrated sweetener approach of the company. The focus of its efforts seems to be the use of enzymes in the production of HFCS. This complements its work in other areas of microbial conversion processes. In collaboration with the British

Atomic Energy Research Establishment new techniques for immobilizing enzymes are being pursued. The first successful one was amyloglucosidase. A 500-L reactor containing this enzyme was in use in the Tate and Lyle Ltd glucose factory. An effort is also being made to develop a commercial process for producing HFCS from chicory, an example of yet another "hedge."

Cane and Beet Factories

Research and development in low-calorie sweeteners and HFCS do not end Tate and Lyle Ltd's research in the sweetener industry. A major effort is also being made to develop improved factory processes for sale to cane- and beet-processing factories. One outstanding innovation for which it has won a British technological award is the TALO process. Although operations in this sector are not a concern of this study, the range of the company's research effort and its base in the sweetener industry approached as a multiproduct industry is definitely highlighted when these activities are noted.

Crop Protection

Long contact with tropical agriculture, and more recently with European agriculture, has stimulated this TNC to exploit its considerable expertise in crop production. Insofar as sucrose-based chemicals may yield important chemical pesticides, part of this effort is integrated with its specialty chemicals activities. The major effort in this field, however, is to use fungi, bacteria, viruses, and other microorganisms to replace, or complement, the use of chemical pesticides. This is an important area of research as many insects and pathogens are becoming resistant to chemical pesticides. The recourse here to the *natural* enemies of these pests obviously constitutes an important endeavour.

Aquaculture

Research and development work in aquaculture seems to be guided by two major considerations. One is the further exploration of the possible uses of water-borne waste materials. The work here, therefore, complements the work on wastes discussed earlier. Second, commercial fish farming is seen as one means of improving food supplies. Tate and Lyle Ltd efforts are aimed at developing a saleable technology in this field.

Research Directions: An Assessment

To be fully understood, the directions of Tate and Lyle Ltd's research, which were highlighted in the previous section, have to be related to the diversification program that the company began just over a decade ago. The variety of research endeavours over the past 12 years falls into one or another of three major categories: food, process technology for producing and processing agricultural crops, and specialty chemicals. All three of these categories in turn find a common origin in the corporation's initial interest in sugar. Diversification for the TNC, therefore, did not mean abandoning sugar but rather there were controlled efforts to build on the spin-offs associated with sugar, either through moving into new areas of activities or into new geographical regions.

From various reports and discussions it seems as if the company has operated or tried to operate with a 10-year time horizon as the "minimum" for achieving best returns on its R&D projects. The projects that were referred to as having reached the commercialization stage, e.g., xanthan gum and TAL detergents, fell within this time frame. The later delays and subsequent abandonment of efforts aimed at commercializing both of these products mentioned here show how important it is not to become impatient toward the end. In the annual report (Tate and Lyle Ltd 1979:14) of the company's New Developments Division for 1979, the position was summed up as follows: "The commercial ventures currently reaching maturity — TAL surfactants, Talin sweeteners, Xanthan gum — represent research goals set a decade ago."

As the report goes on to point out (Tate and Lyle Ltd 1979:14):

> Our long-term research focus is, therefore, on developing the basic chemistry of sucrose and other carbohydrates, and exploring processes for exploiting the potential of biomass as a source of packaged energy. As the basic research advances, the broad approach will converge on identifiable targets on which R and D resources will be concentrated, under the guiding pressures of marketing, environmental, legislative and sociological forces.

If it can be said that the diversification of Tate and Lyle Ltd's operations and its new research and development activities were stimulated by its fear of the dangers associated with its overdependence on a commodity as volatile as cane sugar, these efforts have as yet not developed to a point where wide swings in turnover, assets employed, and profits (losses) have been eliminated. It has already been noted in Tables 38 and 39 how considerable these swings have been. Data on the corporation's profitability (before deductions) are shown in Table 42. These clearly indicate the high level of dependence on sugar that still prevails. Thus, cane sugar production and refining, molasses, and sugar trading accounts for the bulk of the corporation's profits at the end of 1983. These earnings have, however, been quite volatile reflecting changes in sugar prices and refining capacity in the U.K. Thus, in 1978, these profits were as low as 1%. The trend since then, however, has been continuously upward.

After the boom in sugar prices of the mid-1970s a number of factors precipitated a crisis in the company. First there was the inflation of oil prices and the subsequent depression and emergence of a structural crisis in the world economy. This combined with a number of specific features of the company's operations led to a serious decline in profitability. Thus, there was the decline in demand in the U.K. for refined sugar already referred to earlier. Second, the impact of U.K. membership in the EEC on the sugar regime facing the TNC was now beginning to affect the structures of its operations seriously. In addition, there was a demonstrated excess capacity in the starch and glucose industries, a capacity that had been built up during the buoyant years of the sugar boom. There was also in this period a worldwide decline in shipping rates. Finally, the cost of penetrating the North American market turned out to be much higher than the corporation had originally anticipated. These events coincided with the retirement of the then Chairman of the TNC and the assumption of leadership of a new Chairman who was very forthright in advocating the view that to combat the decline in profitability a major restructuring program had to be introduced by the new management.

The restructuring program had five major production and trading elements

Table 42. Tate and Lyle Ltd: trading profit 1978–83.[a]

	1978		1979		1980		1981		1982		1983	
	GBP[b]	%	GBP	%	GBP	%	GBP	%	GBP	%	GBP	%
Agribusiness	4.5	10	2.3	6	(7.6)	(16)	(0.2)	(1)	0.6	1	(0.5)	(1)
Bulk liquid storage	1.4	3	1.2	3	2.9	6	3.0	6	2.3	4	1.2	2
Cane sugar production and refining	1.1	1	7.5	21	17.4	36	24.5	45	30.6	51	44.4	72
Cereal sweeteners and starches	3.3	7	(1.9)[c]	(5)	(1.2)	(3)	(0.6)	(1)	0.4	1	(4.0)	(6)
Commodity trading	17.9	41	9.0	26	16.8	34	9.6	18	5.3	9	4.2	7
Insurance	—	—	0.8	2	0.8	2	1.1	2	0.9	1	1.6	2
Malting	2.0	5	2.4	7	2.3	5	2.0	4	3.3	5	2.3	4
Molasses	6.4	15	8.4	24	15.0	31	10.6	19	12.9	22	7.1	11
Warehousing, packaging, and and distribution	3.9	8	1.9	5	0.9	2	2.2	4	3.1	6	3.6	6
Other activities	2.5	6	2.1	6	1.4	3	2.5	4	0.6	1	2.2	3
Total	44.0	100	35.6	100	48.7	100	54.7	100	60.0	100	62.1	100

Source: Tate and Lyle Ltd, Annual Reports and Accounts, 1978–83.

[a] Profit on ordinary activities before taxation.

[b] GBP million ((GBP = pounds sterling) GBP1.44 = US$1.)

[c] Losses are within parentheses.

to it. One of these was the closure of some sugar refineries in a surgical effort to remove over capacity. The second was to sell and dispose of the corporation's shipping fleet. The third measure was to move out of starch and glucose production in a number of its factories. A fourth was the rather drastic pruning of overheads and central expenditures in the corporation. Last, and of particular significance, a major reappraisal of the corporation's R&D work, and the specialty chemicals program in particular, was undertaken. Accompanying this restructuring program was a major reorganization of the management structure of the TNC, as is usual in such circumstances. As the Chairman put it (Tate and Lyle Ltd 1980a:6):

> Throughout the group we are now setting more urgent requirements for profit return. We have, for example, re-appraised projects for our chemical division on which we are now taking a more conservative view. In surfactants we have decided to write-off our initial expenditure while intensifying our efforts to solve the technical problems we have encountered.

The attitude reflected in this quotation, although making hardheaded business sense, reveals why I raised the question earlier as to whether a company with as volatile a trading structure as Tate and Lyle Ltd can reasonably be expected to sustain the long effort to develop a sucrochemicals industry. On the one hand the volatility of its earnings pushes it on to find a stable manufacturing base in chemicals derived from sugar to ensure a better-regulated sugar demand, but, on the other hand, the very instability of earnings reduces its capacity to finance a long-term research effort. What is, therefore, reflected in the sentiments expressed in the Chairman's statement may be more than the usual pessimism encountered during a downswing of economic activity. It may be the manifestation of this particular dilemma. In any event, the present persistent weakness of sugar prices is adding considerably to the discouragement of the effort in sucrochemicals.

The approach of the new management to the sucrochemicals program was put this way in the corporation's Annual Report for 1980 (Tate and Lyle Ltd 1980a:12):

> To develop and make profitable a new chemicals technology is, we have always acknowledged, to accept a major challenge — particularly at a time of acute depression in the chemicals market. With the added burden of heavy start up expense, we have been in no position to make our planned impact on the market and incurred substantial losses in 1980. It is taking longer than we expected to commission the two new plants of our production complex at Knowsley, Merseyside. With our planned range of surfactant products we have encountered serious technical difficulties and have yet to prove our ability to produce these in volume and on a commercially viable basis. We are continuing our efforts to solve these problems, but in view of the high risk nature of this venture, have written our initial expenditure out of our balance sheet.

Following this announcement, the company has relinquished its share in the biospecialties program and has sold its assets. It has also disposed of a major part of its share in the common services at the Knowsley complex. Its joint venture with Hercules Inc. was also terminated even though recently it concluded an agreement with the chemical TNC, Hoechst A.G., to "work jointly in order to exploit our combined skills in some areas of chemistry and biology" (Tate and Lyle Ltd 1981:4). As the corporation has put it in the same report:

"The agreement combines the experience of a major chemical company and a major food company in developing specific new areas of mutual interest in biotechnology and carbohydrate chemistry."

The examination of Tate and Lyle Ltd shows that, to all intents and purposes, the sucrochemicals program is well and truly at a crossroads. There has been a considerable phasing down of the corporation's efforts in this direction, including the closing down of its chemical division and the absorption of this work in other departments. Despite this, its movement toward joint arrangements with Hoechst A.G. mark an important advance. I say this because that company brings to the agreement not only a wealth of experience in chemical production and trading but being a major "user" itself, it might very well offer the solution to the question of how to penetrate the existing chemicals markets with sucrochemicals.

It should be noted that the downturn in profits which had precipitated the drastic changes indicated above has been halted and a definite upswing in profitability had started during 1981. As the Chairman remarked (Tate and Lyle Ltd 1981:6):

> I am very glad to report that 1981 saw the return of the Tate and Lyle Group to an improved quality of earnings and a more acceptable level of profit — £36.3 million before tax. This result was achieved in a very difficult economic climate, both in the UK and worldwide. It is encouraging to see a stronger group emerging from the drastic policy of rationalisation which we have of necessity pursued in recent years.

Unfortunately, from the standpoint of sucrochemicals this was achieved at its expense. In his Interim Report for the 6 months ending 27 March 1982, the Chairman (Tate and Lyle Ltd 1982) noted the continued upswing in profits, but goes on to point out that: "The containment of expenditure on research and development and substantial reduction of losses in specialty chemicals also has a bearing on the figures."

One note on which this chapter must end is a further reiteration of the observation that a TNC with as volatile an earnings structure as Tate and Lyle Ltd cannot be confidently expected to pioneer a massive breakthrough for sucrochemicals. At the same time, however, a dozen years of sustained research and the commitment of large sums of money to research in this field are an important asset of the company. This TNC is in fact the world-leading institution in the field of sucrochemicals. This considerable asset should not be easily given up or worse wasted. The technical problems that remain in this field are considerable let alone the task of product development and marketing. It would seem as if a new infusion of resources and the opening up of market prospects are needed to get the momentum going again. The question is, however, where will this come from?

Chapter 11

The Threat and the Challenge: An Assessment

Context

In the previous chapters a large amount of detail was given on the development of HFCS and sucrochemicals technology, the structures within which the industries associated with those technical innovations have developed, and the future prospects of these industries. In this chapter, from the perspective of the Caribbean, a general assessment of the impact of these developments will be presented, and certain recommendations will be made. The emphasis here will be judgmental and analytical rather than the repetition of details on market forecasts, trends in capacities, prices, and public policy and the identification of technical obstacles and problems that remain in the development of these technologies.

Certain general propositions about the Caribbean region are implicit in the presentation of the material so far. To erase any doubts, however, that may linger about the context in which my judgments are being exercised and the recommendations made, these will have to be made explicit at this point. The first of the premises is that, historically, arising out of the process of colonization and exploitation by Europe, our agricultural system has been oriented to the production of export staples for consumption abroad. Coming out of the relatively recent process of decolonization, some efforts are being made at the replacement of the foods we eat that are imported from overseas. So far, however, the diversification of agricultural output achieved under the import-substitution program has been rather limited and projections into the future do not indicate any dramatic improvements. This is a particularly depressing state of affairs as the data presented in Chapter I have indicated that within the region the overall food needs exceed domestic supply and current imports of food and feed are within the region of US$1 billion. It is my judgment that in the present state of Caribbean agriculture, significant increases in the output of food would depend inter alia on the following:

(a) Land reform that leads to a socially just distribution of land and other economic resources;

(b) Improved social amenities in the rural areas, e.g., health, recreation, education, training, etc.;

(c) Improved rural infrastructure (roads, drainage, irrigation, and water control, etc.);

(d) The elimination of rural indebtedness accompanied with more appropriate and improved systems of credit;

(e) A substantial decrease in losses of output because of pests and diseases;

(f) A substantial increase in yields and improved regularity of output from presently cultivated areas;

(g) Vastly improved efficiency in the use of fertilizers, water, mechanical equipment, and other energy-intensive inputs;

(h) Better storage, transportation, distribution, and pricing systems; and

(i) Last but not least, improved access to power and the mechanisms of control over their social and political lives by all rural classes, strata, and groups that have been historically excluded from these by dominant minority groups.

Many, if not all the provisions mentioned may well be considered as relevant not only to the Caribbean region but to the world as a whole. Unfortunately, in the latter instance, for those societies in which the improvements can best be afforded, e.g., because there are regular surpluses of agricultural output, they are the least needed, and where they are most needed they are not readily achieved — green revolution notwithstanding.

A second premise is that traditionally the region has been underindustrialized, primarily for the same reason of colonial domination that has determined the export orientation of agriculture and the neglect of internal food demand. Arising out of the post World War II decolonization process, there have been determined local efforts at industrial diversification, mainly by way of programs of fiscal and other incentives designed to substitute imported industrial products with domestically produced ones. In several studies I have already sought to lay bare the essential weaknesses of the industries established in this import-substitution process. Here I will, therefore, simply confine myself to listing some of the major defects (for further discussion see Thomas (1974, 1979, 1982)):

(a) These industries have low domestic value added because of their reliance on the assembly of imported knocked-down equipment;

(b) Their labour absorptive capacity is also low;

(c) There are diseconomies of scale induced by the small and fractured nature of their markets;

(d) Despite small markets, there is significant underutilization of capacity ratings;

(e) The industries create intersectoral links within the national economy and are, therefore, incapable of generating autonomous, self-reinforcing sequences of growth;

(f) Despite substantial capital subsidization the industries are high cost producers that get shelter behind protected markets and use their monopoly status to pass on these costs to their consumers;

(g) Monopoly power is also exerted through the lowering of quality and standards, poor after-sales facilities, and exorbitant financing charges;

(h) The industries, although designed to save foreign exchange, have very high import intensities suggesting at times negative foreign exchange drains from the national economy, despite high private profitability; and

(i) As branches of TNCs, these industries have no serious export interest, except where regional marketing and production conditions make this necessary.

Recently, in some of the larger territories attempts have been made at the development of a basic materials sector, for example Trinidad and Tobago where it is being developed on the basis of its hydrocarbon resources and imported iron ore. These efforts are, however, still very much in their infancy. Nevertheless, I do feel that they constitute an important attempt to overcome the limitations of the import-substituting industrialization process highlighted earlier.

The patterns of agricultural development and industrialization that I have outlined signify a historical process of divergences between domestic resources and domestic production on the one hand and the needs of the population and the market demand for food on the other. Because of this, the bases (both physical and social) for the development of indigenous technology are nonexistent.[5] It was, however, because of this particular historical process of divergencies that I have elsewhere advocated an industrialization model based on the first priority of developing a basic materials sector for the national economy (Thomas 1974:177–227). The essential point of this proposal is that only if we are able to produce those commodities that are needed for the production of all other commodities can we aspire to reverse this historical process of divergencies and end the perpetuation of the dynamic of underdevelopment. The basic commodities used in the production of all other commodities may be indirectly required (e.g., foodstuffs for wage earners) or directly required (e.g., iron and steel). From this criterion a list of the essential industrial products was drawn up, and in this short list of a dozen or so commodities, chemicals appeared (Thomas 1974:195–201).

This, therefore, constitutes the essential context in which the preceding analysis must be seen. The study of sucrochemical technology falls within the scope of the search for an industrial base in what is a relatively abundant regional raw material. Moreover, as indicated in the introduction, the search does not follow the traditional lines of more and more processing of the staple or greater and greater utilization of its by-products. Instead, it examines the frontiers of technological change to see whether advances made there create the possibility of a *radically altered use of a product as traditional as sugar.* The aim, therefore, is to assess whether there is any possibility for a chemical industry based on sucrose as opposed to hydrocarbons, or even other biomass resources, in the context of the more general search for a pattern of investments, growth, output, consumption, and technological change that would be consistent with the development, as against the perpetuation of the underdevelopment, of the

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[5] The thesis here is fully developed in Thomas (1974). The main point of the discussion is merely to introduce the specific location of the sucrochemicals industry in a reorganized Caribbean developmental focus.

Caribbean region. It is clear from this that if a chemical industry based on sucrose could become technically and commercially viable, a significant advance in the cause of Caribbean development would have been made.

The priority search for a capacity to produce the commodities that enter directly or indirectly into the production of all other commodities is not a blueprint for autarchy. It is a program aimed at the creation of an autonomous, self-perpetuating sequence of investments that would internalize the bases of growth and development of the national economy. Furthermore, the success at creating such an internalized system of sequences would be heavily contingent on the availability of foreign exchange with which to finance it. Profitable trade in existing commodities that are being produced is, therefore, a vital requirement of the strategy. In other words, although the search is for new bases of trade in which foreign demand for our output is seen as the extension of domestic requirements, and our own demand for foreign goods is similarly situated, the model specified also seeks to maximize in this context the gains from existing trade patterns. The threat of HFCS to cane sugar should, therefore, be placed in this context of a threat to one of the principal sources of foreign-exchange earnings in the region.

Finally, from the global and regional natural resource point of view, the sources of organic chemicals are oil, coal, and biomass. Because the range of these alternatives is restricted, an important proposition is that the competitive relation between these alternatives is crucial in determining the pattern of resource exploitation. In this competitive relation, I would stress not only price, whose importance should not be underestimated, but other factors such as access and security of supplies, national considerations, degree of monopoly control of production and marketing, environmental considerations, and so on. Initially, the chemical industry switched from biomass and coal to oil because of cheap oil based on huge discoveries, but the recent rapid inflation of hydrocarbons prices, based on their presumed long-run scarcities, has been a major push in the direction of using biomass in general, and sucrose in particular, as a regenerable source of chemicals. The present petrochemical industries, however, possess vast resources and an enormous amount of political leverage. They cannot reasonably be expected to yield their gains or their entrenched positions easily. The successful fight for an alternatively based chemical industry will inevitably require winning significant governmental support for it as a source of countervailing power. Neither the cane sugar industry, as it is globally organized, nor Tate and Lyle Ltd, the major TNC in this field, can reasonably be expected to generate the resources for such a major industrial transformation.

Recommendations

In the study of HFCS in Part I the following was noted:

(a) That there was a slow rate of increase in global demand for sweeteners (2–2.5% per year, maximum). This combined a static or declining per capita demand in the developed countries (usually those where per capita consumption of sucrose is in excess of 45–50 kg/year) and a rising per capita demand in the developing countries (usually those where per capita demand was less than 15–20 kg/year).

(b) In the latter group of countries the drive for self-sufficiency in sugar is strong, and, as a consequence, increased demand does not lead to significantly increased trade. Furthermore, in the former group, countries traditionally thought of as major importers are now major producers and exporters of sugar, e.g., EEC, and this has upset the traditional global demand-supply-trade balances in sugar.

(c) Globally, HFCS output is projected to average about one-tenth of total sweeteners demand by 1990 whereas in its chief growth area, the U.S., output is expected to be substantially higher, as much as 40-45% of demand.

(d) Although projections of the sweetener market have always been fraught with difficulties, there is little evidence to suggest so far that these projections have erred on the side of optimism; to the contrary, for to date output has always exceeded projections.

(e) The growth of HFCS in countries other than the U.S., where the industrial configuration favours it, is heavily contingent on the direction of public policy. The extreme example of this situation is the EEC where, presently, public regulations severely limit the production of HFCS to only 200 000 t/year.

(f) In some Third World countries, HFCS capacity is being installed. Here the emphasis is either on an abundant raw material that can be utilized (corn, rice, cassava) or a large beverages sector to be serviced.

(g) Technically, certain important hurdles need to be overcome before HFCS can completely substitute for sucrose, e.g., crystallization. If these were to be overcome, the rate and pattern of its future growth would be even more dramatic and spectacular than it has been so far.

(h) Summing up, it was concluded in Part I that the major impact of HFCS growth would be felt on international trade in sugar. It was pointed out that only 20-25% cff the world output of sugar was traded internationally and of this 90% was cane sugar. Furthermore, the trade in sugar was riddled with a complex network of bilateral, regional, and international agreements that reduced the "free" world market element to an even smaller proportion of this global output, 2-4%. Traditionally, the price of the "free" market has been subject to wide swings that have made sugar prices notoriously unstable. The conclusion arrived at was that to protect their own consumers or, alternatively, where domestic production of sweeteners takes place, their own producer interests, countries can be expected to restrict imports as a first line of defence if their domestic interests are enhanced or threatened by HFCS growth. In this sense, therefore, the impact of HFCS on cane sugar trade generally and, hence, on the Caribbean in particular, would be far more significant than the output figures of HFCS and other sweeteners would alone suggest.

On the basis of the foregoing observations, two major recommendations were made at the end of the survey of HFCS. The *first recommendation* was that a strong case could be made for an ISA that covers all sweeteners — caloric and noncaloric. This was advocated as a position for the Caribbean to adopt. It was pointed out in support of this idea that the HFCS producers also had an interest in a world sweetener market that was less volatile and unstable, and, therefore, this interest should be encouraged in every way. In so far as the volatility and instability of sugar prices stem from the peculiar "free" market structure for sugar, the inclusion of all major forms of sweetener production, whether traded or not, into an international sugar agreement is necessary to ensure orderly marketing of all sweeteners.

The recommendation, therefore, envisaged not only the incorporation of other sweeteners into the present ISA, but the transformation of the ISA itself into a more general and comprehensive framework in which to plan the production and marketing of all major forms of sweeteners. To the extent that this recommendation aids the formation of a regime of remunerative and stable prices for reasonably efficient sugar producers, it also promotes a basis on which the planned utilization of sucrose as a chemical feedstock might be developed. In other words, all actions that make for a more orderly and stable marketing of sucrose, ipso facto also make more orderly and stable conditions when promoting its use as a chemical feedstock. From the viewpoint of science and technology planning this recommendation, therefore, seeks to suggest ways that might stabilize the production and marketing conditions of sucrose to encourage its development as a major raw material input.

The *second recommendation* made was that the Caribbean region should spare no efforts in developing a monitoring capacity to identify and so permit a planned response to developments in HFCS output and technology. Two points were made with regard to monitoring. One was that it should be seen as systematic intelligence gathering — a necessary function that falls within the framework of national and regional S&T planning. To reinforce this comment at that point I was careful to identify the function of what I termed monitoring (searching for "signals" that are indicators of significant innovation; identifying the probable consequences of these innovations, choosing the context in which one could identify the speed and direction of the technology and the effects of its use, presenting the above data in a timely manner to ensure that effective reactions can be made by management on the basis of an assessment of it). The second point that was made was that for monitoring to be effective it had to embrace all forms of sweeteners. Traditionally, cane sugar producers have focused on the monitoring of each other's activities with some occasional studies of developments in beet sugar. What is called for here is the incorporation not only of HFCS but other sweeteners, e.g., the low calorie and noncaloric sweeteners into a systematic framework of intelligence gathering. In the particular case of the two examples cited here, the important point was made that a threat that overhangs cane and beet sugar as well as HFCS itself is the possible discovery of a low calorie sweetener with the taste and other major characteristics of sucrose.

Monitoring as an aspect of national and regional S&T planning should be extended also to include the entire field of sucrochemicals activities. In other words, both "the threat and the challenge" have to be thoroughly comprehended if a satisfactory regional/national response is to be made. This, therefore, constitutes my *third recommendation*. This monitoring has to be institutionalized and put on an ongoing basis. It cannot depend on occasional studies.

The particular importance of this recommendation to the Caribbean is laid bare when we take into account how mature and ossified the cane sugar industry has become and how limited has been its research focus and interventions on sugar issues in the region. There is much truth in the observation of Hagelberg and Ahlfeld (1981:3) on both the beet and cane sugar industries:

> Secure until recently from competition by close substitutes, the industry has felt little need for product development, beyond the immediate areas of refining quality, liquid sugar and dry bulk shipment. While the value of beet pulp and of beet or cane molasses on occasion may have meant the difference between profit and loss, they have remained by-products.

The authors go on to point out that:

> For all the renewed interest in fermentation alcohol brought about by escalating oil prices, beet and cane are still grown primarily to produce sugar, and sugar is still used almost exclusively for human consumption, although periodically there has been significant diversions.

The authors then go on to cite the production of high-test molasses in Cuba between 1935 and 1958, and the use of fodder sugar in the EEC during the late 1960s and early 1970s, as examples of these "diversions."

Whatever may be said, it seems to me that the lack of innovative drive and imagination in the Caribbean sugar industry is largely attributable to the protection and susidies that have been afforded the sugar planters by various Caribbean and colonial office governments. Over the centuries the economic and political power commanded by the region's sugar planters has been enough to ensure them considerable leverage concerning every state policy and they have used this leverage with extreme single-mindedness in the pursuit of their narrow interests. In pursuit of their goals, they have been aided by the fact that sugar is a very labour-intensive activity in the region and, as such, it has been easy to make any threat to the profitability of sugar quickly translatable into a threat of retrenchment and unemployment affecting the livelihood of hundreds of thousands of West Indian people. As soon as this spectre was presented to governments, they have invariably come to the rescue of the sugar planters.

The study presented here is in many different ways an initial effort at monitoring developments in the field of sucrochemicals generally and Tate and Lyle Ltd's activity as the leading TNC in particular. It cannot be considered, however, as either being complete or being itself a substitute for an ongoing regional mechanism to provide this science and technology planning function. In the previous chapter however, I did stress that the future of sucrochemicals was at an extremely critical juncture. After more than a decade of consistent research and development work, Tate and Lyle Ltd has retreated over the past 2 years. Although I did point out its efforts to form a partnership with Hoechst A.G., and suggest that this was a hopeful step, it is still true that the expertise and marketing resources required to penetrate the petrochemical dominance will require not only more resources but a more stable earnings basis than Tate and Lyle Ltd, based as it is on sugar, can command. Yet, paradoxically, as pointed out before, it is this same dependence and vulnerability caused by its sugar-based industrial structure that has sustained the TNC's efforts as a breakthrough in sucrochemicals.

Whatever significance may be attached to the present study it cannot be a substitute for an ongoing process of monitoring. Already more than 2 years have elapsed since this study was substantially completed and circulated (October 1983). Yet to date, regional reaction has been modest, although the sugar technologists' association of the Caribbean did invite me to speak at the plenary of their conference held in March 1985 on this topic.

My *fourth recommendation* stems from the belief that at this juncture an injection of entirely new resources and the creation of new market opportunities are required to get the momentum in favour of sucrochemicals started again. Because I have pointed out that ultimately only government policy can ensure the required countervailing power to that exercised by the petroleum TNCs, my recommendation is that the governments of the region, at a regional level, should consider an agreement aimed at joint research, technology, development, production, and marketing of sucrochemicals with Tate and Lyle Ltd. Such an agreement should cover research in progress, new research and development work being contemplated, as well as the licencing of production of sucrochemicals in the region. It is of course reasonable to expect that through public policy market development for these products can be guaranteed by licencing, etc. To support this endeavour a regional *venture capital fund* and a legal entity to operate it should be created and financed out of a levy on sugar production. The idea of a sugar levy of this sort is of course not new, because after World War II the colonial authorities introduced this in several territories in the region, creating three funds, one of which was directed toward the rehabilitation and recomposition of the capital stock then available to the sugar industry. The difference between then and now is that the recommendation here involves deliberate risk taking and, hence, the notion of a "venture" capital fund to finance these activities. It is my strong belief that although Tate and Lyle Ltd is presently at a crossroads, this is the most opportune time to pursue an equitable arrangement.

Creating a venture capital fund of this sort is by itself insufficient for the purposes at hand. What is also needed is a planned effort to develop an indigenous research capability in this field to ensure that in these arrangements there is a *science transfer*, that is "the know-why, know-how, and know-who" of sucrochemistry (Dedijer 1983:30). The following suggestions therefore, constitute my *fifth recommendation*. Ultimately, what is needed is a shift in the present research focus of sugar. These efforts should not only include sucrochemicals activity but should also cover such other areas as fermentation technology (linked to a possible gasohol program), food technology and carbohydrate uses, process technology in the sugar factories, and cane sugar harvesting and logistical operations. Such a shift in focus would require that the region's training facilities be appropriately geared, and a good starting point here would be to grant postgraduate training awards and fellowships to persons in the Caribbean. From this program a corps of persons equipped to offer courses at university level in those fields can be created. As this is taking place, laboratories and other research facilities can be built up incorporating those of existing regional institutions, e.g., Cariri. Gaps in resources that are identified can then be filled by the appropriate importation of skilled persons. Along with those efforts a proper documentation centre should also be built up, with the aim being for this centre eventually to take over some of the basic monitoring functions indicated in the third recommendation.

One area of this activity that I believe is of some urgency, and that underscores a failure of this study, is the need for on-the-spot monitoring of activities in sucrose chemicals and HFCS from carbohydrates other than corn, which are taking place in other Third World countries. Such activities occur in an environment much closer to ours and the problems encountered in their relationships with the TNCs, the construction of facilities, and actual production and marketing difficulties will be of salutory value. In other words, we may be able to learn from others' mistakes if we treat such developments in the Third World as a "social laboratory" to be closely monitored. In the literature, it is remarkable how many Third World countries have repeated the same mistakes others have made through ignorance.

In conclusion, I should perhaps reiterate an earlier observation that, although my study does not encompass the use of sucrose as a source of energy, ultimately the role of sucrose in this regard in the region will be crucial. As has been noted the fermentation technology for ethanol production is not new, although many improvements have taken place affecting yields, residence rates, quality of the substrates in which the microorganisms are cultivated, etc. The production of ethanol on a large scale might be feasible in a gasolene-extender program with the use of "excess" ethanol as a chemical feedstock. To my mind, this route to sucrose chemicals could only be a preferred route in the context of such an overall approach. Otherwise, directed synthesis is the preferred route. The question, however, that I want to refer to here is what would be the impact on regional food supplies if land were directed toward sucrose chemicals? The answer is simple. A sucrose-chemicals program that does not envision large-scale gasolene-extender production will not require large amounts of sucrose. Indeed, when we realize that the region's current output of sucrose is about 60–70% of the region's capacity to produce sugar, then the program need not even require the diversion of export sales to service it.

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